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JOHN C. MERRIAM

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Vol. 6, No. 1, pp. 1-19 Issued November 28, 1910

THE CONDOR-LIKE VULTURES

OF

RANCHO LA BREA

BY

LOYE HOLMES MILLER

BERKELEY

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

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CONTENTS.

OCCURRENCE, AND NATURE OF MATERIAL.

The conditions which prevailed during the formation of the Rancho La Brea Beds seem to have been especially favorable for the entrapment and preservation of the remains of large vultures. The presence there of an abundance of beautifully preserved material referable to the vulture group is doubtless the result of a variety of causes.

A consideration of the factors involved leads to their discussion in three general categories: (1) richness of fauna; (2) attractiveness of the locality to vultures in particular; (3) favorable method of preservation.

RICHNESS OF FAUNA.

There is every evidence that the Quaternary fauna representing this group was very rich both in species and in individuals, a condition doubtless due in large measure to an abundant food supply. Climatic conditions probably were effective only through their influence upon that potent factor. The abundance of food is attested by the large number of mammalian remains found in the asphalt, remains both of carnivores and herbivores, many of which were of large size. There appears to be a more or less intimate ecological relation between the large scavenging bird and the large predatory mammal, in addition to the more obvious relation between the latter and the large herbivore. The herbivore, slain and partially devoured by the carnivore, becomes the natural food of the large vulture; its thick skin and its resisting tissue rendering ineffective the efforts of the less powerful scavengers.

At present in this region the sole surviving vulture of gigantic size is *Gymnogyps californianus.* Before civilized man became a disturbing influence, the deer, the panther and this condor doubtless formed an important ecological group. The soundness of this premise is attested by the difficulty with which early California hunters kept the condors from carcasses hung up or cached for food. With the advent of civilized man the large native mammals such as deer, elk, antelope, and mountain sheep as well as their natural enemy, the panther, began to decline rapidly in numbers. Some in fact were practically swept into extinction. The compensating influence of the introduced domestic animals was insufficient to restore the original condition because trap, gun and poison were directed at both carnivore and scavenger. As a result in some measure of this change the California condor is now one of our rarest birds.

Whatever influences may have conspired in Pleistocene time to carry the sloth, bison, horse, the saber-tooth and the lion from the field were also effective in the extinction of most of the scavengers so intimately dependent upon them. The gigantic *Teratornis* and most of his somewhat smaller associates were obliged to yield their places to forms that could subsist upon

smaller quarry. The evidence from Rancho La Brea bears out the otherwise very natural conclusion that *Gymnogyps californianus* was far more abundant at the time these beds were formed than it is at present.

ATTRACTIVENESS OF THE LOCALITY.

The attractions offered at the asphalt beds during the entombment of Pleistocene forms were probably more effective with the vultures than with any other bird group. Vultures are not averse to fresh meat, and according to Finley[1] prefer it to carrion. The Andean condor is reported to follow and attack disabled animals[2]. The author has seen the turkey vulture, (*Cathartes aura*) drive the marsh hawk (*Circus*) from its prey. At another time one of these birds was surprised feeding upon the body of a skunk from which the fresh blood ran. Without much question the bird had killed this rather inactive animal which depends for defense upon a weapon ineffective with the vultures. It would thus appear that the struggling victim of the asphalt might have formed an especially attractive lure for the vulture. The lure, however, did not become ineffective with the cessation of the animal's struggle or even with its partial decomposition. The bait was thus out for the scavenger longer than for the more distinctly predaceous raptor.

According to uncontrovertable evidence obtained by Mr. Joseph Grinnell of the University of California, in trapping for foxes with concealed bait, the turkey vulture is attracted by the smell of its food and great numbers of these birds were caught in his steel traps. Darwin's experiments with Andean condors indicate the reverse to be true of that species, yet it is not impossible that the odors emanating from the asphalt pits were attractive to vultures.

Owing to the above causes the entombment of the vultures became a matter less fortuitous, perhaps, than has been the case in many other fossil deposits where the indefinite multiplication of

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1 Finley, W. L., *Condor*, 12, Jan. 1910, p. 5.

2 Prichard, H. H., "*Through the Heart of Patagonia*," Appleton & Co., N. Y., 1902, p. 191.

the factor of chance was the chief assurance that a representative series of specimens would be assembled. The asphalt trap thus so continuously baited throughout a considerable period of time probably approaches very nearly in effect the efforts of a conscious and persistent collector of today. Toll was taken from a large area if we may judge by the wide-ranging habit of large vultures of today. Through the keen senses of these birds the lure was effective at great distances. The trap was practically automatic, its demands insatiable, and its patience unwearied.

PRESERVATION OF MATERIAL.

The mode of preservation of the asphalt material was especially favorable in the case of the condors. While still in the live state the bone was plunged into the soft tar which effectively sealed it from the air. With the maceration of soft parts, the asphalt slowly penetrated the bone even to its minutest structure. There was in most cases no period of weathering before entombment, no erosion through stream or wind action, no gnawing by rodents or crushing by wolf or fox. In asphalt masses which were shallow at the time of entrapment the entire body of the animal was not embedded at once. With birds, after struggling ceased, the feather covering often may have kept the carcass from complete submersion for some time. Cases are noticeable among specimens recently entrapped in shallow outflows where the sacrum, dorsal region and the back of the skull show extensive weathering while the limbs, sternum, and the basal and facial parts of the skull were perfectly impregnated. That such condition was less frequently the case with the condors seems highly probable. Their natural prey, the large mammal, was entrapped only in outflows of appreciable depth, a depth at least sufficient to immerse the condor entirely. The violent struggles of these powerful birds, of which more than one was usually entrapped about a single carcass, would tend to effect the speedy interment of the entire body. The slow sinking of the mammalian carcass would tend to carry down the bird's body as well.

The large mammal, though entrapped in a comparatively shallow tar pool, probably became submerged fairly rapidly on

account of the quick maceration which would set free the parts of the skeleton. When covered with the thick, oily asphalt, there is no drying of the carcass, but the soft parts, under the action of putrifactive bacteria, simply break down in their own protoplasmic fluids. Such conditions favor the rapid settling of the entire skeleton into the matrix.

The close proximity of the entrapped condor to the body of its prey was probably not infrequently influential in its more perfect preservation. Shielded by the tabular bones of the large mammal the more fragile bones of the bird were often saved from being fractured by the victim next blundering into the pool.

The firm texture of bird bone, its high degree of pneumatiacity, permitting the rapid penetration of the larger cavities by the asphalt, the large size and relative robustness of the condors, all served as factors conducive to the preservation of the remains of these birds. Considering the general conspiracy of favorable conditions, we may look upon the condor material from the asphalt as representing the Pleistocene condor fauna of this region with a remarkable degree of accuracy.

DESCRIPTION.

The part most commonly preserved among the birds is the very dense and powerful tarso-metarsus. Of this segment there are at least twenty-five nearly perfect specimens and a number of fragments. The amount of Recent material for comparison is limited to one specimen each of *Gymnogyps* and *Sarcorhamphus*.

This dearth of comparative material is especially deplorable in view of the large size of the species, which would naturally be expected to follow the tendency of large mammals to vary to a marked degree. The large series of fossil specimens however supplies in a measure this lack of Recent material.

A careful study of the tarsus of *Sarcorhamphus* as represented by a small specimen from the Museo de La Plata, and close attention to an account of the large specimen in the Museum of Princeton University by Dr. W. J. Sinclair, show the osteological differences between the North and the South American condors to be inconspicuous so far as the tarsus is concerned.

Both exhibit a marked degree of flattening of the bone, a character found also in *Cathartes, Catharista* and *Gypagus. Cathartes* and *Gypagus* show perhaps the extreme of this condition, *Gymnogyps* occupies an intermediary position, while *Sarcorhamphus* and *Catharista* display it to a minimum degree. The deep furrowing of the anterior face of the shaft is likewise a common character and a character which somewhat closely parallels the preceding one in its variation with the different genera. Both characters remain quite constant for a given species if *Cathartes* and *Gymnogyps* may be considered as representative. Width of shaft in relation to width of extremeties seems to vary perceptibly with age. The articular surfaces seem to attain full size while the shaft is yet comparatively slender.

An examination of representatives of the five genera of Recent cathartids, which ornithologists group into two subfamilies, shows a greater homogeneity of characters of the tarsus than is displayed by the series of twenty-four condor-like tarsi from the asphalt beds. Even casual examination shows that this series of fossils falls easily into four distinct groups. The group containing the largest number is considered to be specifically identical with the Recent *Gymnogyps californianus.* The second series, consisting of two specimens, compares most nearly with *Sarcorhamphus,* to which genus it is tentatively assigned. In the absence of larger series for the study of variation in either form, the entire significance of the differences between the fossil and the Recent forms of *Sarcorhamphus* is hard to determine. It would seem best under the circumstances to consider them of no more than specific importance. The other two groups of the series show such extensive divergence from all of the known genera as to make the establishment of new genera for their reception the only consistent step possible.

GYMNOGYPS CALIFORNIANUS (Shaw).

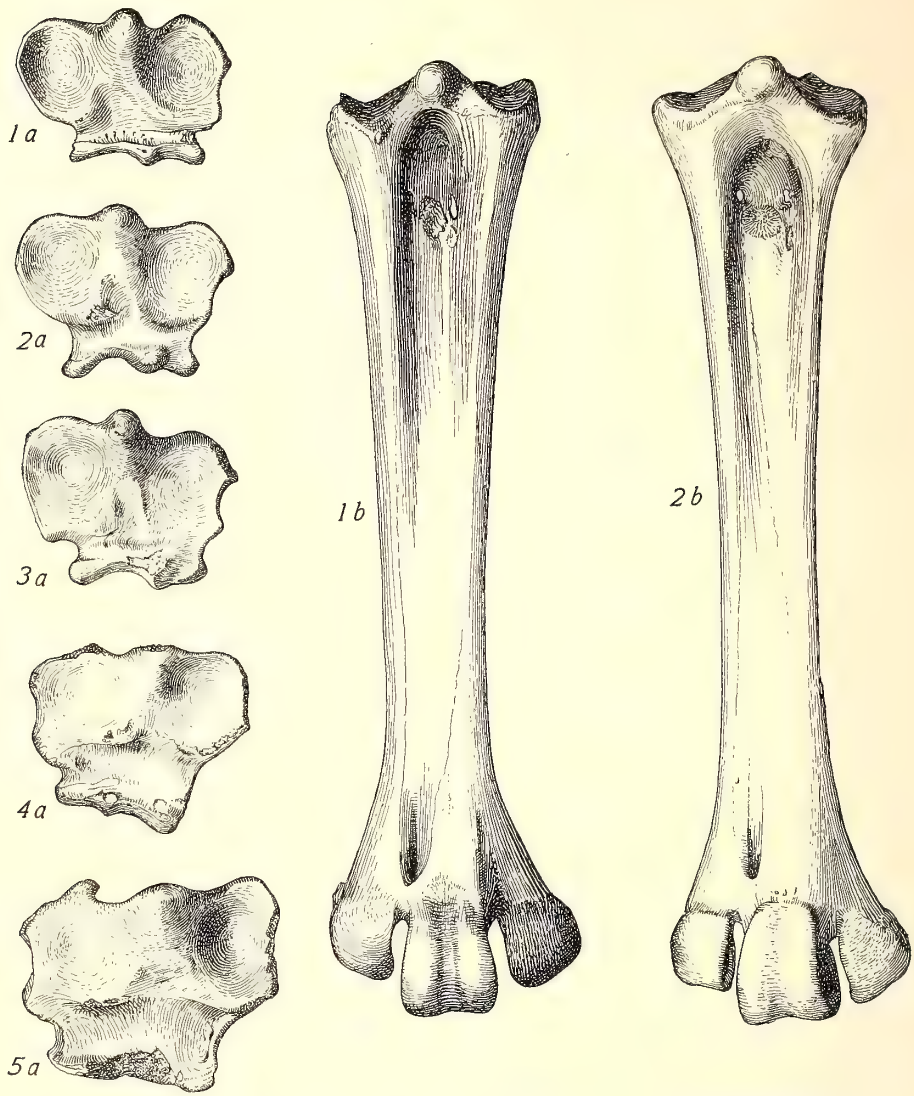
A series of fourteen specimens of the tarsus represents the existing Californian species. In this series the homogeneity is remarkable and altogether sufficient to obviate the necessity of a greater series of Recent skeletons. The series is assigned

without reserve to the existing species *Gymnogyps californianus.* Careful scrutiny fails to show any important difference between any member of the series and the single available specimen of the Recent form. This Recent specimen consists of the tibiae, tarsi and wing bones of a male bird presented by Mr. Otto Zahn of Los Angeles, California. The bird was taken in Santa Barbara County, California, and was said to be a large male. The only dimensions obtainable from the specimen as it came to the author's hands were the wing and tarsal lengths. These were 29 inches and 4.50 inches respectively. Coues records the wing measurement as 24 to 36 inches and the tarsus 4.50 to 5.00 inches. This bird thus appears to have been about the average in size and, as the females are not larger than the males, probably represents the species fairly well.

All the fossil tarsi of this species are larger than the Recent specimen—with total lengths ranging from 120 to 131 mm. The Recent specimen measures 116.8 mm. in length. A typical member of this series of fourteen bones is No. 12161, a description of which is here inserted:

Typical specimen.—No. 12161, Univ. Calif. Col. Vert. Palae. Tarsometatarsus taken from Rancho La Brea beds at a depth of 6 feet 4 inches. The specimen is a typical cathartine tarsus measuring 126 mm. in total length, with a maximum transverse shaft diameter of 13.9 m. m. Viewed from in front the head shows a prominent rounded intercotylar tuberosity rising between the facets of the tibial condyles. The sides of this tubercle slope abruptly down to the border of the external facet and more gradually to the internal facet. Below this tuberosity the shaft is deeply excavated by the proximal part of the anterior furrow which here reaches its widest and deepest development. Two foramina here pierce the bone from anterior to posterior passing through to open, one internal and the other external to the hypotarsus. In the median line the furrow is slightly interrupted by an irregular rugosity for the attachment of the tibialis anticus. Except for this slight interruption the anterior furrow becomes very gradually narrower and shallower as it passes down the shaft. At about three-fourths the way down, this furrow, by a very slight deviation toward the exterior, passes almost insensibly into a furrow leading to a foramen piercing the bone just proximal to the outer intertrochlear space, the distal foramen, through which the adductor tendon to the outer toe and the anterior tibial artery pass. At no point in its length does the anterior face of the shaft cease to be at least slightly concave transversely.

At its distal end, where the bone widens out to the distal trochleae the inner profile is concave on a shorter radius than is the outer. This



The proximal articular and the anterior aspect of tarso-metatarsi described. All figures approximately natural size.

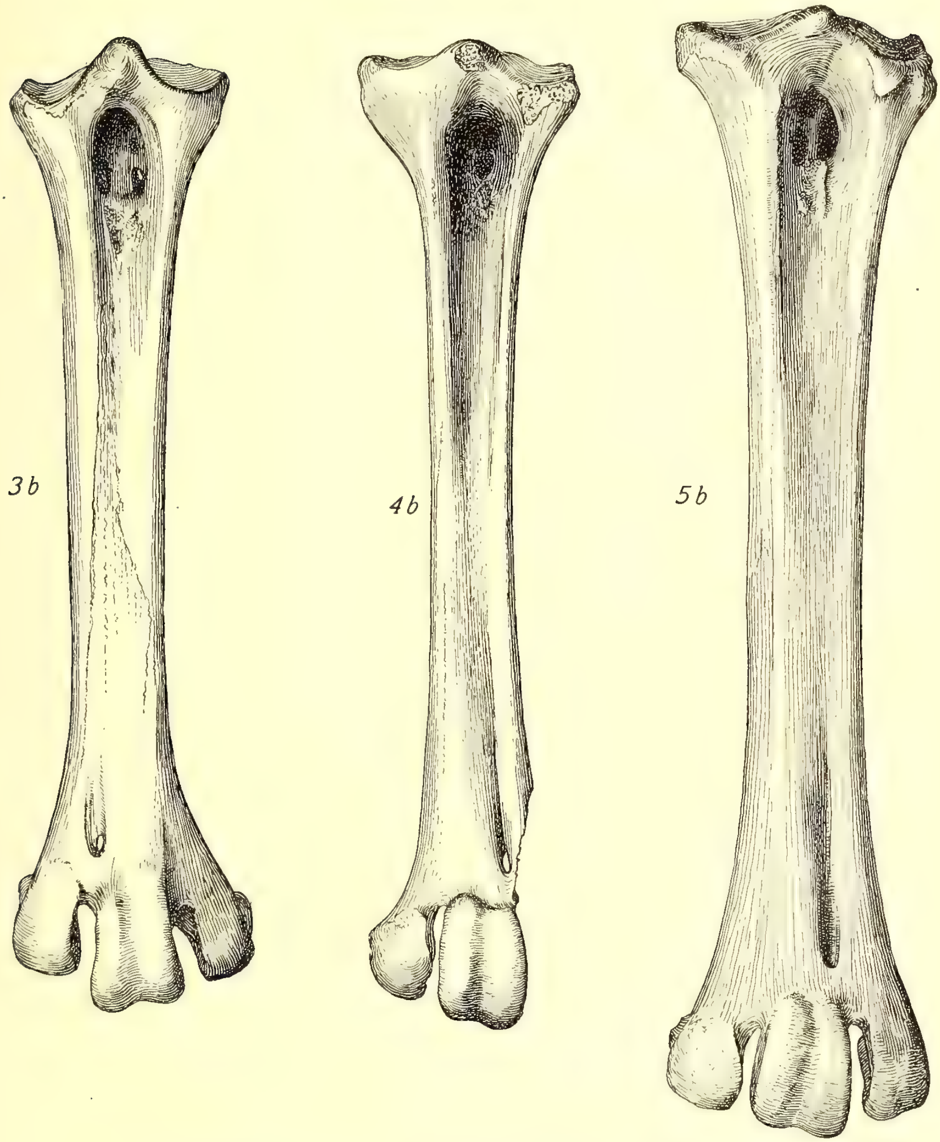
Figs. 1*a* and 1*b*. *Gymnogyps californianus.* No. 12161.

Figs. 2*a* and 2*b*. *Sarcorhamphus gryphus,* from a specimen obtained from the Museo de La Plata.

Fig. 3*a*. *Sarcorhamphus clarki.* No. 12588.

Fig. 4*a*. *Cathartornis gracilis.* No. 12598.

Fig. 5*a*. *Pleistogyps rex.* No. 12599.



Anterior aspect of tarso-metatarsi. All figures natural size.

Fig. 3b. *Sarcorhamphus clarki.* No. 12588.

Fig. 4b. *Cathartornis gracilis.* No. 12598.

Fig. 5b. *Pleistogyps rex.* No. 12599.

gives the erroneous impression that the inner toe is set farther from the middle of the foot than is the case with the outer toe. The outer profile begins to trend away from the central axis sooner than does the inner border and thus the concavity is more gradual. The two lateral toes are on almost the same level and show but slight discrepancy in size.

Passing down the middle of the shaft at the bottom of the furrow is an intermuscular line. Its proximal end arises near the rugosity of the tibialis anticus just external to the median line. Thence it trends downward and inward, crossing the median line slightly above the middle point of the shaft. At a point about three-fourths the way down, it crosses the median line again in a more positive curve to divide into an inner and an outer branch going to the inner and outer intertrochlear spaces. A second intermuscular-line occupies the summit of the outer ridge of the anterior furrow for about the middle half of its length.

As seen from the rear, the head bears the great mound of the hypotarsus, roughly triangular with its longest side almost horizontal but declined toward the exterior, its most obtuse angle in the median line downward, its shortest side facing downward and outward. Its face is divided nearly on the median line by a low ridge into a larger internal concave surface and a smaller external concave surface. On either side of the hypotarsus the bone is excavated abruptly, thus leaving the hypotarsus concave on either side parallel to the sagittal plane.

From the median line of the hypotarsus a high rounded ridge passes down the shaft for about one-fourth its length to merge into the flat posterior surface of the shaft. In the region of the trochlea the palmar surface is only slightly concave. The perforation for the anterior tibial artery seems very small.

The ridges passing down this aspect of the tarsus are three in number. An inner and an outer limiting ridge pass from the corresponding extremeties of the head to the inner and outer trochleae. A median ridge starts on the external side of the hypotarsus, trending still farther outward to return to the median line just above the foot. The line throughout its length thus remains very slightly concave from the inner side.

A view of the proximal articular surface shows the two facets subequal in size with the outer slightly the larger. The outer facet is longest in a plane parallel to the sagittal, the inner in a plane inclined about forty-five degrees with the sagittal plane. Posterior to the intercotylar tubercle lies a broad depression opening backward toward the hypotarsus where it merges into a narrow and sharply defined transverse groove separating the hypotarsus from the head. Seen from this direction the hypotarsus seems almost block-like. Its margin toward the head marked by the almost straight groove, its lateral margins slightly concave and its posterior margin marked by two slight concavities. This block appears fastened to the head nearer to the outer side than to the inner.

The view of the trochleae from the distal end shows the arch of the foot to be very slight and the inner toe but little behind the outer, The middle trochlea is very symmetrical. Its groove occupies the median

plane of the shaft almost exactly and shows no deflection to either side. The inner trochlea is second in size though but slightly larger than the outer. The two intertrochlear spaces are about equal.

Table of measurements of *Gymnogyps californianus* taken from a series of fourteen tarsi excavated at Rancho La Brea.

	Maximum.	Minimum.	Average.
Total length over all	131.4 mm.	120.0	123.7
Least transverse diameter of shaft	15.0	13.2	14.28
Sagittal diameter at middle of shaft	11.2	8.8	10.1
Greatest transverse diameter of head	30.1	26.5	28.01
Greatest transverse diameter through trochleae	33.2	30.7	32.09

SARCORHAMPHUS CLARKI, n. sp.[3]

Type specimen 12588, Univ. Calif. Col. Vert. Palae. Tarsometatarsus.

Shaft narrower and more nearly cylindrical than in *Sarcorhamphus gryphus,* less excavated in front: intercotylar tuberosity more prominent; proximal foramina much nearer together.

The type specimen was excavated at Rancho La Brea by the author in an exposure fifty feet north of that worked by the University of California. It was added to the University collection and taken as the type of this species because of its perfect preservation. It is here compared with a specimen of the present species *S. gryphus* from the Museo de La Plata. The Recent specimen bore no data as to age or sex. The facial part of the skull was still covered with the natural skin. There appeared no caruncular outgrowth and a sparse, hairlike feathering was just evident. This suggestion of immaturity is offset by the firm ossification of all the bones and normal size of the tarsal foramina. If *Sarcorhamphus* resemble *Gymnogyps* in the feathering of the head during the first two or more years of life, this specimen might be assumed to represent a bird in its second to fifth year of age. Youth of the individual in *Cathartes* reduces the tarsus in its actual size and in its relative width. The specimen of the Recent *Sarcorhamphus* at hand, then, may be assumed to display a greater degree of slenderness in the

[3] This species is named in honor of Dr. F. C. Clark of Los Angeles, Calif., in recognition of valued assistance rendered by him in the studies here recorded.

tarsus than would be found in the average of the species. Compared with this Recent specimen, the type of *Sarcorhamphus clarki* shows many of the same points of difference that are brought out in comparison with *Gymnogyps*, i. e., slenderness of the shaft and its nearly uniform width throughout most of its length; by its high intercotylar tuberosity and the narrow partition separating the two proximal foramina.

The two bones are almost identical in length, which makes comparison easier. The view of the two specimens from the anterior side shows the fossil form to differ in the following details: The inner tibial facet is raised farther above the outer one, the intervening tuberosity is larger and more globular. The diameter of the shaft contracts more suddenly just below the head. The excavation of the shaft in the head region is more abrupt and more restricted. The partition separating the two proximal foramina is not more than two-thirds as wide. The attachment of the tibialis anticus blocks the whole anterior furrow which is continued down the shaft on a shallower level to disappear entirely before reaching the middle point of the shaft. The narrowest point of the shaft is at or above the middle point instead of below it. The actual width of the shaft is markedly less. The foot is narrower, the trochleae are longer but more slender.

Seen from the outside, the tuberosity appears more knob-shaped. The hypotarsus is placed higher and its outer ridge is less pronounced. The lateral margin of the outer articular facet drops downward and forward more abruptly. The shaft from this aspect is appreciably thicker throughout its length. The outer trochlea appears less stubby.

From the posterior and internal aspects no important differences are noticeable other than have been recorded above.

When viewed from the tibial end, the greater anteroposterior diameter of the head is noticeable. The inner articular facet is larger and its greatest diameter lies in a plane more nearly parallel to the sagittal plane. The triangular space posterior to the tuberosity is nearly equilateral and not longer on its anteroexternal face. The groove separating the hypotarsus from the head is shallower and less perfectly defined, especially at its external end. The posterior profile of the hypotarsus is much less deeply indented.

The specimen was also compared with *Gymnogyps californianus* Recent specimen. The fossil form is distinguishable by much the same characters as were noticed in its comparison with *Sarcorhamphus gryphus*. The total length of the bone is ten millimeters greater and the breadth at either end exceeds that of *Gymnogyps*, yet the shaft is markedly narrower at all corresponding points throughout its length. The lateral toes

also are raised slightly higher. Details of comparison show the differences to be quite marked.

Viewed from in front, the shaft is excavated at the head end in a deep pit enclosed on all sides by abrupt walls. Even in the region of the attachment of the tibialis anticus this depression is completely leveed and the anterior furrow of the tarsus passes down the shaft on a plane much less deeply placed than the floor of the proximal depression. This anterior furrow extends less than half way down the tarsus. At its middle point the shaft is not concave from side to side. In the Recent form the whole anterior face is occupied by a broad depression, abrupt at its proximal end, only slightly interrupted by the insertion of the tibialis anticus and passing almost insensibly into the groove leading into the foramen for the adductor tendon of the outer toe. The outer border of the furrow in the fossil form gradually merges into a well-defined ridge which becomes most noticeable at the middle portion of the shaft. Thence it is deflected outward and skirts the border of the foramen of the adductor of the external digit. In the Recent form no such ridge is visible. The narrowness of the shaft and the fact that the transverse diameter is nearly constant for so great a part of the length, makes the curvature very abrupt at either end where the bone widens for its articulations. This is especially noticeable in case of the inner profile at the proximal end.

Seen from the side the greater thickness of the shaft is at once noticeable. The trochleae are larger. The greater thickness of the head is quite apparent as is the greater size of the intercotylar tuberosity. The attachment of the articular ligaments is raised into more of a tubercle. The hypotarsus is slightly higher on the shaft.

Seen from the rear, the narrowness of the shaft is again evident. The longitudinal limiting ridges are thrust toward each other in the middle portion. The median ridge coming down the shaft from the hypotarsus curves over to the inner side until it makes a line concave from without. The facet of the accessory metacarpal is placed relatively higher up the shaft. The lateral toes are likewise placed higher. The hypotarsus is set off less abruptly from the general plane of the bone.

Seen from without, this latter feature becomes evident in the head region by the less marked concavity in the region of the internal proximal foramen. In *Gymnogyps* the bone is very thin in this region and the internal longitudinal ridge of the shaft passes up fully to the tarsal head.

A scrutiny of the facets of tibial articulation brings out very markedly the distinction between the two forms. The two facets in *Sarcorhamphus clarki* are almost equal in size and both are longest in their antero-posterior axes. In *Gymnogyps californianus*, the outer facet is longest in its transverse axis while the inner is longest in a line at nearly forty-five degrees with the sagittal plane. The depression between the articular surfaces just back of the tubercle is not so deep, so narrow nor so obliquely distorted in *S. clarki*. The transverse furrow separating the hypotarsus from the head is not so deep nor so well defined in the fossil form.

TABLE OF MEASUREMENTS.

Tarso-metarsus.

Total length	127.1 mm.
Greatest transverse diameter of head	27.3
Greatest sagittal diameter of head	22.8
Greatest transverse diameter through trochleae	29.6
Greatest transverse diameter of middle trochleae	12.1
Greatest sagittal diameter of middle trochlea	16.9
Least transverse diameter of shaft	12.4
Sagittal diameter at middle of shaft	10.0
Width of partition between proximal foramina	4.0
Transverse diameter of pit into which proximal foramina open	7.6
Longitudinal diameter of same	11.9

CATHARTORNIS GRACILIS, n. gen. & sp.

Type specimen No. 12598 and cotype No. 12600, Univ. Calif. Col. Vert. Palae. Tarso-metatarsus.

Extremely slender front of shaft strongly grooved throughout its length. Inner ridge of hypotarsus much the more prominent.

Shaft of tarsus relatively narrow and thick, the excavation in front below the head very deep, abrupt and subcircular. Intercotylar tuberosity relatively inconspicuous. Tibial facets subequal and with their longest diameters nearly parallel to the sagittal plane. Hypotarsal block set well toward the outer side of the head and with the inner edge much the more prominent. Hypotarsus separate from the head by wide smooth depression, as seen from the proximal end.

This group, third in the entire series of tarsi, consists of two specimens, a right and a left, taken at the same depth and section of the excavation. Their identity of characters suggest very strongly their having belonged to the same individual. The specimen from the left side has suffered the loss of the outer trochlea and part of the anteroexternal border of the head. The other specimen lacks the entire head and parts of the three trochleae have been lost by corrosion. The character of the bone is firm with good surface and the foramina of the head are well defined, thus indicating that the bones represent an individual fully mature.

The species is distinguishable at a glance from the other condors by its extreme slenderness. The total length exceeds that of any of the specimens referred to *Gymnogyps californianus* but its shaft is actually very much narrower. Unlike the modern condors the shaft

remains nearly uniform in diameter until very near the head, where it suddenly expands. This expansion to the head however is mainly on the inner side, a condition which throws the center of the head far to the inner side of the axis of the shaft and gives this end of the bone a markedly goose-like appearance. The intercotylar tuberosity is very low and flat with gradual slopes in all directions. It has scarcely half the development seen in *Gymnogyps* and *Sarcorhamphus.* The excavation of the shaft just below the head is deep and almost perfectly elliptical. The attachment of the tibialis anticus appears as a pair of distinct papillae below which the trough in the shaft is very deep and almost "U" shaped in cross section. The edges of the trough are thus converted into very narrow ridges. The furrow continues down the shank to merge into the distal foramen. There are no intermuscular lines evident on the anterior face, though the shaft here shows no corrosion. The shaft widens very gradually to the foot and cotype No. 12600 shows the two sides to be very nearly symmetrical in curvature. This condition is in marked contrast with the asymmetry of the proximal end and with the condition in the foot of *Sarcorhamphus* and of *Gymnogyps.*

The two trochleae remaining on the type specimen are much more slender than in the existing condors. In their anteroposterior planes they exceed both the above mentioned species but the degree of lateral compression is very great. The posterior surface of the shaft presents an aspect very similar to that in *Sarcorhamphus clarki* except that it is still more narrow, more gradually tapering and the intermuscular line is poorly defined. The surface between the two longitudinal limiting crests is strongly convex as far down as the distal foramen.

A view of the proximal articular surface brings out some very characteristic features of the species. The tuberosity is scarcely evident from this direction, the outer articular facet is but little if at all in arear of the inner one and both facets have their longest axes almost parallel with the sagittal plane. The depression posterior to the tubercle is scarcely evident and the depression separating the hypotarsus from the head is almost obsolete. The inner ridge of the hypotarsus projects backward almost twice as far as does the outer one and the inner margin of the hypotarsal "block" has the appearance of having been thrust over toward the outer side. The posterior profile of the hypotarsus is much as in *G. californianus* except as tilted outward by the more prominent inner border.

TABLE OF MEASUREMENTS.

Tarso-metatarsus.

Total length	131.4 mm.
Greatest transverse diameter of head	26.6
Greatest sagittal diameter of head	25.00
Greatest transverse diameter of middle trochlea	11.6
Greatest sagittal diameter of middle trochlea	19.9
Least transverse diameter of shaft	11.2
Sagittal diameter at middle of shaft	11.2
Width of partition between proximal foramina	2.2
Transverse diameter of pit into which the proximal foramina open	6.00
Longitudinal diameter of the same	9.00

PLEISTOGYPS REX, n. gen. and sp.

Type specimen No. 12599, Univ. Calif. Col. Vert. Palae. Tarso-metatarsus.

Size very large. Intercotylar tuberosity very inconspicuous. Head almost symmetrical upon the shaft. Foot narrow and rotated inward; inner toe much in rear of outer and reaching almost the same level as middle toe. Groove of middle trochlea not in sagittal plane.

This last well defined group in the series of tarsi assembled consists of five specimens representing at least four, and probably five, different individuals. The superficial appearance is most nearly like *Sarcorhamphus clarki* but closer scrutiny renders any confusion impossible. *S. clarki* stands as the smallest of the entire series and the present species is at the opposite extreme in size. The relatively narrow foot, the inconspicuous intercotylar tuberosity and the less flattened shaft and head, serve to differentiate the form at once from *Sarcorhamphus* and *Gymnogyps.* The greater robustness, the more symmetrical head and the narrow, intoed foot distinguish it readily from *Cathartornis gracilis.*

Front aspect.—The head region is excavated much as in *C. gracilis* but the cavity is smaller and more nearly circular. To the outer side of the cavity just below the margin of the outer articular facet, there appears a large round headed tubercle. To the inner side of the cavity and at a slightly lower level than the upper limit of the cavity there appears a small, sharp papilla. The intercotylar tuberosity, as above mentioned, is low and mound-shaped. The attachment of the tibialis anticus takes the form of two papillae, the outer elongate one placed slightly above the inner, more nearly circular one. Below these papillae the shaft is moderately excavated, the lateral margins appearing as smoothly rounded ridges. The outer ridge becomes more sharply angled as it nears the middle portion of the shaft, and despite the fact that the anterior furrow here becomes practically obsolete passes thence as a definite ridge almost straight to the outer border of the distal foramen. The narrowest place in the shaft is at just about the middle point. From this point, the enlargement in either direction is quite gradual. The curvature on the inner side at the foot region is slightly greater than on the outer side. In the head region, the curvature is almost equal on both sides. The trochleae reach more nearly the same level than in any of the species hitherto discussed. The inner trochlea, in fact, descends almost to the same level as the middle one.

Further marking of the face of the bone is limited to a single longitudinal intermuscular line which begins on the outer side of the outer tubercle of the tibialis anticus, passes rather quickly to the median line, and leaves the median line at about the middle of the shaft to pass over to and occupy the inner border, where it disappears at a point about three-fourths the way down the tarsus.

Posterior aspect.—Viewed from this direction No. 12599 most nearly approaches *S. clarki* in appearance. The general profile at the head end is at right angles to the axis instead of being raised at the inner border. The intercotylar tuberosity is almost invisible. Externally a sharp break in the profile is produced by a high and pointed tubercle situated at the posteroexternal point of the outer articular facet. The hypotarsus is slightly lower than in *C. gracilis* and, unlike the forms previously described, the lower border of the hypotarsus does not merge into the longitudinal ridge at the back of the shaft. Instead of being roughly triangular the hypotarsus is more nearly a quadrangle. Its distal margin is a well-defined transverse ridge elevated distinctly above the median longitudinal ridge of the shaft. The limiting ridges and intermuscular line are much the same as in *C. gracilis.*

The plantar opening of the distal foramen is very large and is placed very low, so that in the type specimen its distal margin breaks down into the external intertrochlear space. This character is constant in the series of four specimens. In a corresponding position above the inner intertrochlear space there appears a rounded depression, found in all specimens of the species and marking the entry into the bone of one or more foramina which are probably nutrient in nature.

Proximal articular surface.—From this point of view several interesting features are noticeable. The two articular facets are relatively short in their anteroposterior axes, yet the head seems deep in this direction because of the unusually wide, smooth depression between the articular portion and the hypotarsus. The tubercle on the anterior border of the outer facet throws this portion of the anterior profile of the head out beyond the convexity of the intercotylar tuberosity and renders the profile between these two points abruptly concave. The anterointernal margin is again produced but more gradually until it reaches a point slightly beyond the intercotylar tuberosity.

The external border of the head is marked by three salient points, the first near its anterior limit, the second at the posterolateral limit of the external facet, and the third at the posterolateral extremity of the hypotarsus.

The posterior margin of the hypotarsus does not differ essentially from the same profile in the other condors. The inner hypotarsal ridge is produced to a slightly less degree than is shown in *C. gracilis.* The inner profile of the bone from this point of view is very much like that of *gracilis.* The most prominent point is very near the posterolateral margin of the inner facet. From this point the outline sweeps backward and centrally in an open curve to the internal margin of the hypotarsus. The intercotylar tuberosity from this direction is scarcely visible, its margins are so ill defined. The depression which commonly

appears just posterior to the tuberosity cannot be definitely outlined. The depression between the head proper and the hypotarsus is a very broad shallow and smooth area marked off on all its borders by raised ridges. In none of the other species does this condition appear so entirely fulfilled.

TABLE OF MEASUREMENTS.

Tarso-metatarsus.	
Total length	149.6 mm.
Greatest transverse diameter of head	34.5
Greatest sagittal diameter of head	27.00
Greatest transverse diameter through trochleae	34.6
Greatest transverse diameter of middle trochlea	13.2
Greatest sagittal diameter of middle trochlea	19.8
Least transverse diameter of shaft	15.8
Sagittal diameter at middle of shaft	12.3
Width of partition between proximal foramina	2.9
Transverse diameter of pit into which the proximal foramina open	7.0
Longitudinal diameter of the same	9.0

A consideration of the large size and the cathartine affinities of *Teratornis merriami* naturally raises the question of possible assignment of the present series to that species. There are several considerations which seem to the author to render such procedure inadvisable. The discrepancy in size between *Sarcorhamphus gryphus* and *Teratornis merriami* as represented by the skull and the pectoral girdle is greater than is exhibited by the tarsi at hand. It seems far from logical that *Teratornis* with its powerful raptorial beak should have had especially weak feet, since the food of the bird must have been such as to demand its coming to earth or to perch at least while the prey was being devoured. The throwing of the large body into the air upon resuming flight would seem to demand a development of the pelvic limb at least proportional to that of the existing condors. If the foot of *Teratornis* were in harmony of character with the powerful predatory beak, it would be prehensile and offensive. The shank would under those circumstances be very stout, and deeply concave on its posterior face, for the flexor tendons and the transverse plantar arch would be more pronounced. In the face of thus much evidence, it seems improbable that no. 12599 could belong to *Teratornis merriami*.

I am very deeply indebted to Dr. Wm. J. Sinclair of the geological department of Princeton University for a careful comparison of the type specimen with a large specimen of *Sarcorhamphus gryphus* taken near Coy Inlet, Patagonia, and at present in the collection at Princeton. The fossil form is but slightly larger than the Princeton specimen but its other characters show the species to be totally different. *Sarcorhamphus* resembles very closely the California *Gymnogyps*, except for its greater size. The high intercotylar tuberosity, the wide excavation of the shaft in front at the proximal end where the internal and external proximal foramina are widely separated, the anteroposterior flattening of the shaft and the distribution of its intermuscular ridges, the positon and configuration of the hypotarsus—all these points ally *Sarcorphamphus gryphus* very closely with *Gymnogyps californianus* and distinguish it absolutely from any of the fossil forms.

In view of the conditions favoring the existence of a large number and variety of condor-like forms during the Pleistocene and of the many instances of known intermigrations of North and South American forms, it is interesting to note the absence thus far of *Sarcorhamphus gryphus* and *Gypagus papa* from the asphalt collections. There seems little or no evidence of migration of individuals of these large species, yet within the time of ornithological record both the South and the North American species have been forms of widely extended range.

The figures reproduced in this paper are from drawings by Mrs. Louise Nash.

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TERTIARY MAMMAL BEDS

OF

VIRGIN VALLEY AND THOUSAND CREEK

IN

NORTHWESTERN NEVADA

BY

JOHN C. MERRIAM

PART I.—GEOLOGIC HISTORY

BERKELEY

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PART I.—GEOLOGIC HISTORY.

CONTENTS.

INTRODUCTION.

The Tertiary fossil beds of northwestern Nevada were first brought to the writer's attention in 1905 through Mr. Robert L. Fulton, who kindly permitted the examination of several fragments of bones and teeth obtained in Virgin Valley by Mr. Allan C. Bragg, and given by him to Mr. Fulton. In the attempt to obtain information regarding the geology of the region, the late John A. Reid, then Professor at the University of Nevada, assisted in every possible way.

In June, 1906, the writer, in company with Felix T. Smith, a student at the University of California, made a reconnaissance of the Virgin Valley region and obtained a small collection of fossils. In a brief statement of the results of this study published by the writer[1] the formation in Virgin Valley was designated as the Virgin Valley Beds. It was considered as Miocene, with the suggestion that the upper part of the series was probably not older than the Mascall stage of the John Day region.

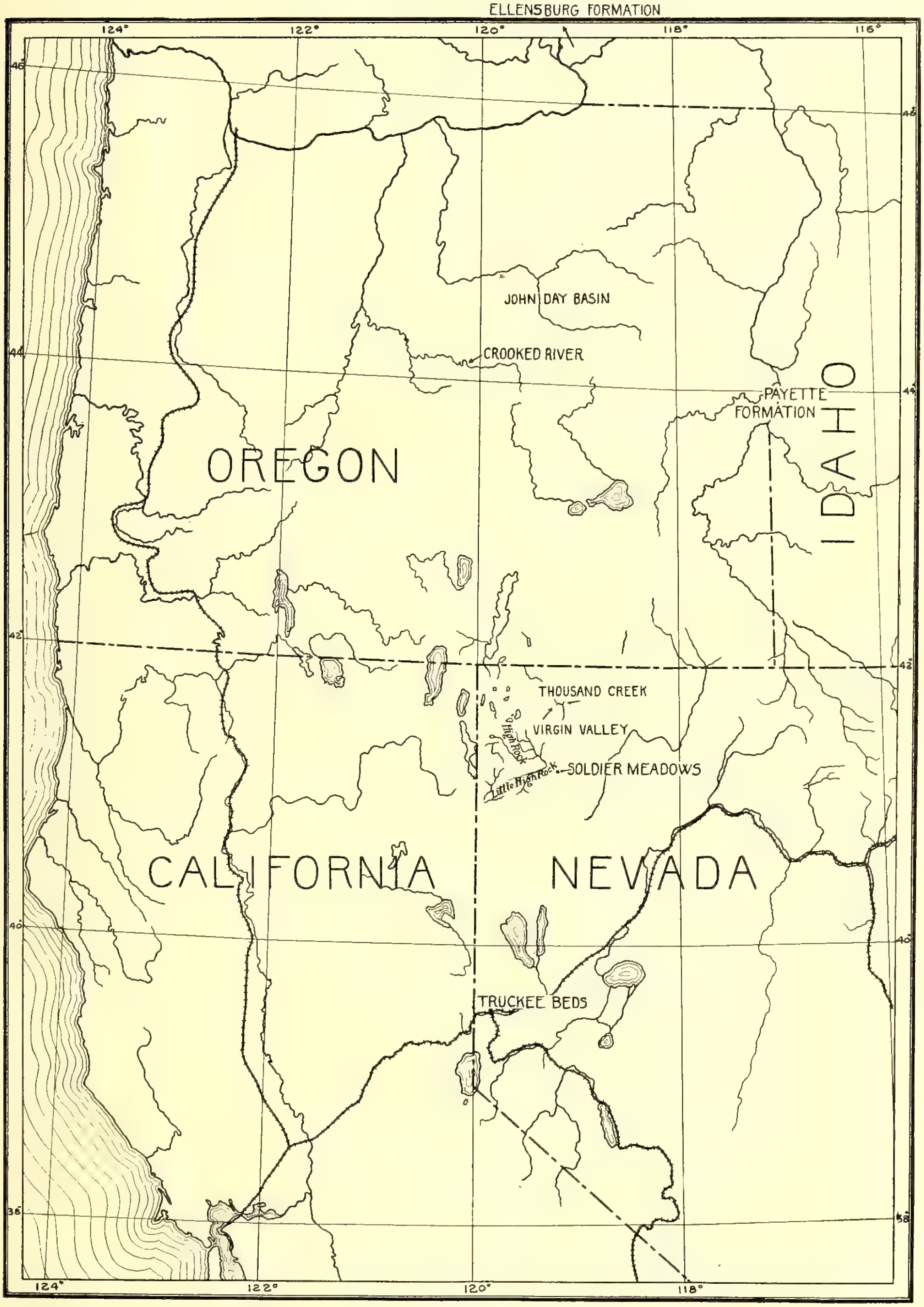
In a discussion of some of the ungulate material collected largely in the older beds at Virgin Valley by Merriam and Smith in 1906, J. W. Gidley[2] expressed the opinion that all of the specimens in the collection examined represented middle or lower Miocene, and that they might be somewhat older than the Mascall.

In the summer of 1909, Miss Annie M. Alexander very kindly offered to organize and finance an expedition to Virgin Valley to carry on the work which had been suggested by the reconnaissance in 1906. The party organized by Miss Alexander spent three months in the field, and after working over the exposures at Virgin Valley and Thousand Creek, the exploration was extended to several localities near Soldier Meadows to the south of Virgin Valley, where a number of new exposures of mammal beds were discovered.

The available information relating to the mammal beds of the Virgin Valley and Thousand Creek region is presented in

1 Science, n. s., 26, pp. 380-382. Sept. 20, 1907.

2 Univ. Calif. Publ. Bull. Dept. Geol., 5, p. 242. 1908.



Outline map showing situation of the Tertiary mammal-bearing beds of northwestern Nevada.

two parts issued separately. The first part includes a general description of the region, a history of investigation carried on there, and a discussion of the geologic history. The second part contains a discussion of the extinct mammalian faunas of these beds, with a consideration of all the accumulated information contributing to an understanding of the age of these faunas and of the formations in which they are found.

ACKNOWLEDGMENTS.

In presenting the following report on the work of the 1909 expedition in northwestern Nevada, the writer wishes to express his indebtedness to Miss Annie M. Alexander for making the expedition possible through its financial support, and for the personal interest with which the field work was carried on under difficult conditions. The writer is also much indebted to Miss Louise Kellogg, who joined in the field work with Miss Alexander and materially contributed to the success of the party.

During the field operations E. L. Furlong devoted special attention to the occurrence and distribution of the mammalian remains obtained, and to the nature of the mammal beds. Mr. Furlong also had immediate charge of the fossil collections. A. J. Heindl brought together a representative collection of rock specimens illustrating the principal lithological phases of the formations occurring in the region investigated, and made a series of notes on their occurrence and structure.

In carrying out the work of the expedition the Pacific Live Stock Company, through all of its representatives with whom the members of the party came in contact, most generously assisted in every way possible, and contributed greatly to the efficiency of the expedition. Particularly in connection with the work in the field, mention should be made of assistance by Mr. F. M. Payne, who was very helpful to the party.

The writer is also indebted to T. H. McGhee and Edward McGhee of Virgin Valley for information regarding the occurrence of fossil remains. It should be stated that Edward McGhee is, so far as known to the writer, the first person to discover fossil bones in Virgin Valley. On the reconnaissance trip made

by the writer in 1906 T. H. McGhee very kindly indicated to us the situation of some of the most important fossil localities in the region.

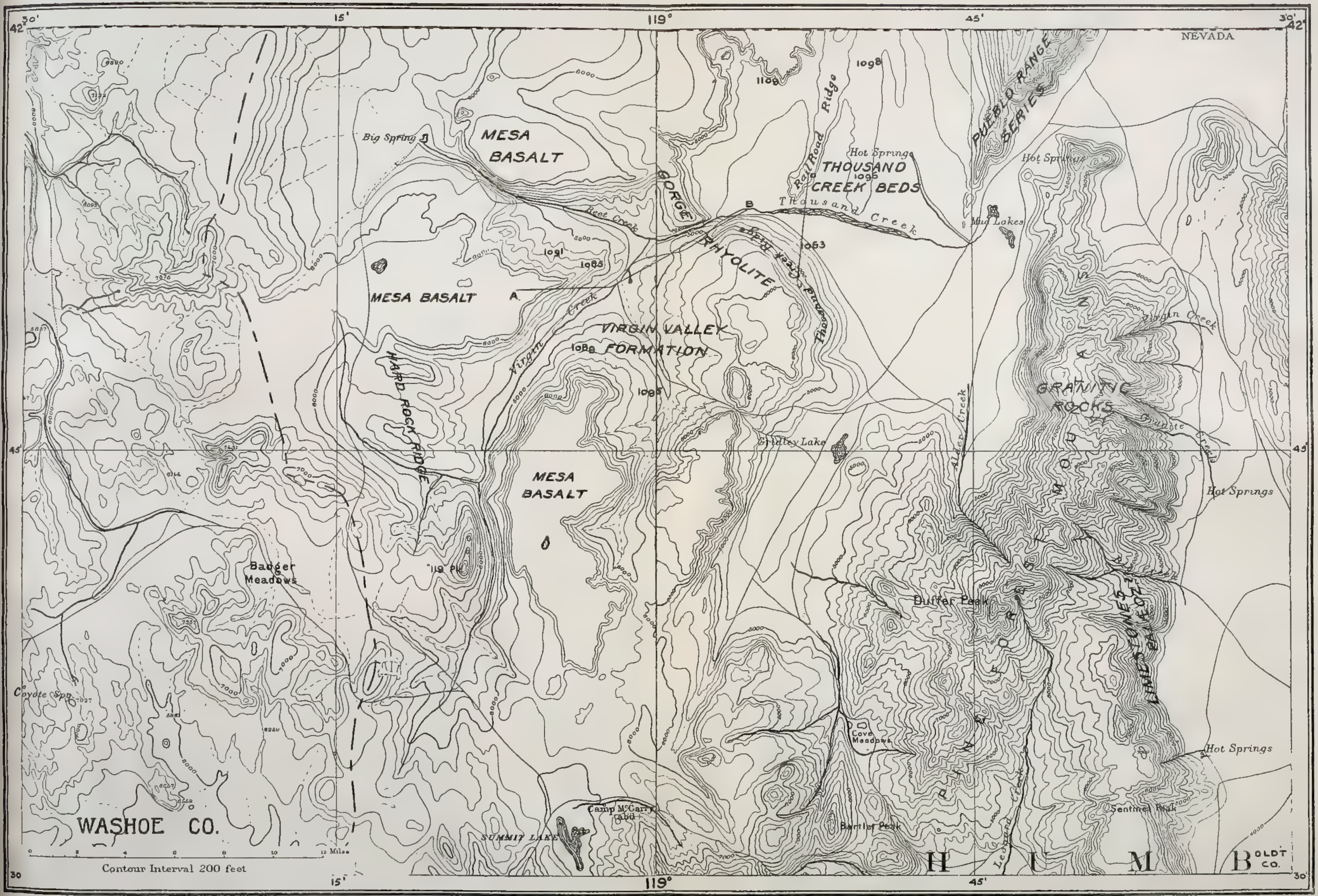
GENERAL PHYSICAL FEATURES OF THE REGION.

The region in which the mammal-bearing beds of Virgin Valley and Thousand Creek are situated lies between two fairly defined areas of quite different topographic nature. To the east and south there is a succession of sharply defined mountain ranges with a general north and south trend, between which are broad and remarkably flat valleys. The Pine Forest and Pueblo ranges, which form the eastern border of the region in which the principal field work was carried on, rise to a height of over 9000 feet. The broad valleys have an elevation of about 4000 feet.

As is so frequently shown in the Basin region, the development of the mountain chains to the east of Virgin Valley is evidently due in a large part to faulting. The remarkably even filling of the valleys was accomplished in part by alluvial wash, and partly by accumulation in lakes. A series of terraces distinctly shown bordering the flats near Sodhouse Point and near Mason's Crossing, in the valleys immediately to the east of Pine Forest Range, represents the shore-line of a body of water which must have covered a large part of the valley floor in this region during some portion of Pleistocene time. Associated with the terraces are remnants of marginal deposits containing a fresh-water molluscan fauna. Along certain levels, the marginal deposits of the ancient lake show an extraordinarily heavy calcareous deposit. According to Russell[3] this region was occupied by the northern extension of Lake Lahontan, and the terrace deposits to which reference has just been made were evidently formed during that period of deposition.

In the region to the west of Virgin Valley the country is largely lava-covered, and is evidently a southward extension of the great lava plateau in the Oregon region to the north. The valleys here are either broad and comparatively shallow depres-

[3] Russell, I. C., Lake Lahontan, Monog. U. S. Geol. Surv. no. 11. 1885.



Contour map of region about Virgin Valley. Adapted from U. S. Geological Survey topographic maps.

sions, due to crustal movements of less magnitude than those which produced the deep, broad valleys to the east; or they are comparatively narrow cañons due to erosion. The general level of this region is much higher than that of the broad valleys to the east.

The region under consideration may be classified, as a whole, as semi-arid, excepting some of the highest zones of the larger mountain masses. Over the greater part of the area sage-brush is the dominant type of vegetation. Trees are almost entirely absent, excepting scattered junipers on the hills, a few alders and willows along the streams, and a few pines in the highest zone.

Notwithstanding the generally arid nature of the country, there is sufficient grass, and other vegetation which may serve as food for herbivorous animals, to support a large mammalian population. In comparatively recent time the ungulates have been quite abundantly represented by prong-horn antelope, deer, and mountain sheep. At the present day the carnivores are numerously represented by coyotes, wild-cats, and badgers, and an abundant rodent population includes many genera and species. The fauna as a whole is surprisingly rich in variety of forms and number of individuals.

GEOLOGIC FEATURES OF THE REGION.

The geologic features of the region visited by the expedition present a most attractive study. A considerable number of well-defined formations are represented and numerous instructive sections are exposed by extensive fault-scarps and deeply eroded cañons. The district immediately surrounding the field examined apparently shows a range of geological systems extending from Palaeozoic to Quaternary.

As the primary object of the expedition was to obtain a representation of the mammalian fauna of the sedimentary formations in the Virgin Valley region, the acquisition of palaeontological material was the occupation of first importance. Investigation of the formations represented has therefore of necessity been confined almost exclusively to the fossil-bearing beds with those adjacent to them, and may not be considered as more than a reconnaissance.

In the region investigated, five fairly distinct geologic sections were examined; *viz.*, those of Pueblo Range, Pine Forest Range, Virgin Valley, Thousand Creek, and High Rock Cañon. For the purpose of description these sections are discussed separately.

PUEBLO RANGE SECTION.

Previous to the brief note published by the writer in 1907[4] the only reference to the geology of the region near Virgin Valley known to have been published is that of Blake[5], in 1875, on the Pueblo Mountains, extending southward along the east side of the Thousand Creek region (pl. 2).

Blake described a section of the beds across the Pueblo Range which corresponds very closely in its upper portion with a profile of the southern extremity of this range made by A. J. Heindl, and confirmed by the independent observations of E. L. Furlong and the writer in passing through this region. According to Blake, the lowest formation is a ''porphyry'' which is overlain on the east side by ''metamorphic rocks, principally micaceous and talcose schists with some metamorphic limestones. These have a dip of about 78° E. with a strike generally North 16° E. They appear to have been thrown up by an eruption of porphyry, which now forms the crest of the ridge.'' The western portion of the section is formed by a ridge which overlaps the eastern ridge both at its north and south ends. The western ridge was described as ''composed entirely of volcanic rocks, arranged in regular strata, with a dip of 20° to the west. They form perfectly conformable layers, and extend from its base to the summit of the ridge, a height of more than 1200 feet, 6,000 feet above the level of the sea. The beds are composed of many varieties of volcanic rock.'' The section of the western ridge consisted mainly of basalts below, with trachytic rocks at the top. At the southern end of the ridge Blake observed strata considered as of aqueous origin. ''They were laying perfectly conformable on volcanic rocks and were covered in by a layer of gray trachyte also perfectly conformable

[4] Science, n. s., 26, p. 380. Sept. 20, 1907.

[5] Blake, J., Proc. Calif. Acad. Sci., 5, pp. 210-214. 1875.

with these aqueous beds. The beds were about 200 feet thick, consisting of strata of white and red argillaceous rocks, rolled conglomerate, and were all evidently formed from debris of volcanic rocks, the conglomerate being made up principally of rolled pumice.''

Blake pointed out particularly that the succession of igneous rocks, in which basalts occurred below trachytes, did not agree with Richthofen's system. He also expressed the view that ''the geological formation of this range will be found to be repeated in the vast outflows of volcanic rocks that cover so large a portion of Eastern Oregon, extending north beyond the Columbia River.''

No definite evidence of the age of any of the formations was given by Blake, though he suggested that the erupted rocks were early Miocene, and that the older rocks of the eastern ridge were probably Triassic.

Waring[6] in his account of the Geology and Water Resources of the Harney Basin Region, Oregon, refers to the work of Blake and speaks of the Pueblo Mountains as ''composed of rocks that belong to an older series than do the lavas to the north. These mountains were only cursorily examined, but from float specimens that were collected along the eastern base of the range they appear to be made up of andesitic porphyries, micaceous schists, and granitic rocks, which have been more or less extensively affected by mineralizing agents.''

In Waring's paper on the Harney Lake region, the geology of an extensive area to the north of Virgin Valley and Thousand Creek has been outlined. Unfortunately the geologic mapping was not carried to the southern end of the Harney Valley sheet on Waring's map, but was discontinued about twenty miles north of the Oregon line. The northernmost point reached by the University of California expedition in 1909 is situated near the southern border of Oregon.

The section at the southern end of the Pueblo Range was examined in detail by Heindl in the ridge opposite Mud Lakes. At this point a thickness of about eleven hundred feet in the

[6] Waring, Gerald A., U. S. Geol. Surv., Water-Supply Paper, 231, p. 18. 1909.

upper portion of the series is exposed by a sharp fault along the west side of the lake. The beds here dip at an angle of about twenty degrees to the north of west. The section as obtained by Heindl is shown in figure 1.

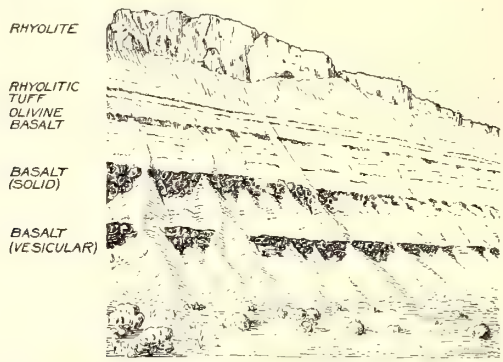


Fig. 1.—Cliff section showing a portion of the Pueblo Range Series immediately west of Mud Lakes.

As nearly as can be determined the sequence here agrees with that observed by Blake[7].

To the west of this extension of the range there is a considerable thickness of ashes and tuffs resting upon the beds exposed at Mud Lakes. Above these ash beds are still later eruptives which Heindl believes to be rhyolite. This portion of the section presumably corresponds to the upper portion of Blake's section showing beds considered to be of aqueous origin. According to Blake the beds of supposed aqueous origin were conformable with the volcanic rocks below them, and were covered by a layer of gray trachyte, also conformable. The sedimentary beds consisted in part of conglomerate which was made up largely of rolled pumice.

Seen from some distance to the south, the great series of the Pueblo Range eruptives and the associated beds appears as a remarkable example of evenly tilted strata, extending back toward the mountain core by regular steps as each hard stratum is passed. The whole series runs under the plain of Thousand Creek to the west with a fairly uniform dip of approx-

[7] Op. cit. 1875.

imately twenty degrees. In all of the localities in which the mammal beds of Thousand Creek have been observed they are nearly horizontal. Though no observations have been made at their actual contact with the older formation, there would seem to be a strong angular unconformity between the two.

Whether the sedimentary beds in the upper portion of the Pueblo Range section actually belong with the lavas and tuffs below is not certain. They, with the lavas, appear to represent one general period of deposition. At all events they both antedate the period of deformation which preceded the deposition of the Virgin Valley and Thousand Creek beds.

For practical purposes it is desirable to refer to the rhyolites and basalts on the western side of the Pueblo Range, with whatever eruptives or other beds may be shown to belong in the same series, as the Pueblo Range Series, a geographic designation indicating the section first described by Blake. This section is geographically so situated that it should be possible to correlate it with other igneous series in the region of southern Oregon and northern Nevada. To this series the Cañon Rhyolite bordering Virgin Valley apparently belongs, although it is not entirely certain whether it represents exactly the same horizon as the rhyolites exposed in the upper part of the section immediately to the west of Mud Lakes. A careful study may show the Pueblo Range Series to be composed of several fairly distinct divisions.

PINE FOREST RANGE.

Corresponding in a manner to the observations of Blake on the Pueblo Range, the work of the University of California expedition has shown that the prominent mountain mass known as the Pine Forest Range (pl. 2) which overlaps the southern end of the Pueblo Range, comprises a granitic mass bordered by rock series which have undergone considerable alteration in many cases. On the eastern side of the southern end of the range there are extensive exposures of limestone which appear from a distance as a grayish band running obliquely up the mountain slope from the south. In this exposure Miss Alexander obtained a considerable number of specimens made up largely

of round crinoid stems. Although the crinoid fragments are insufficient evidence upon which to base a definite age determination, the presence of stems of this character probably indicates that the beds are older than the Triassic, as the most abundant Triassic crinoids of this general region are not of the round-stemmed type. The presumption is that the limestones are Carboniferous, though there is no definite evidence that they are not older.

The sides of the Pine Forest Range are flanked by series of igneous rocks that apparently correspond in a large part to the Pueblo Range Series represented by such extensive exposures on the western side of the Pueblo Range immediately to the north.

VIRGIN VALLEY SECTION.

The geologic section exposed in Virgin Valley is the most important examined, as the larger part of the known Tertiary history of this region is illustrated here in excellent exposures. At least three formations are represented, of which the middle one is the mammal-bearing series known as the Virgin Valley Beds. The Cañon Rhyolite immediately underlying the mammal beds is presumably of the same age as the upper or rhyolitic portions of the Pueblo Range Series. The Mesa Basalt, which overlies the Virgin Valley Beds, is widely spread over the surrounding region. (See fig. 2).

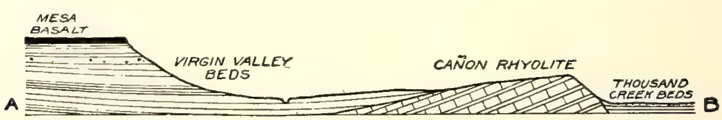


Fig. 2.—Section along A-B line on plate 2, showing section across Virgin Valley and Thousand Creek Ridge.

The structure of the beds in Virgin Valley is in general synclinal. The basal formation, the Cañon Rhyolite, dips southwest and beneath the valley from Thousand Creek Ridge to the east; and reappears, dipping northeast, in Hard Rock Ridge to the southwest. The Virgin Valley Beds form a shallow trough,

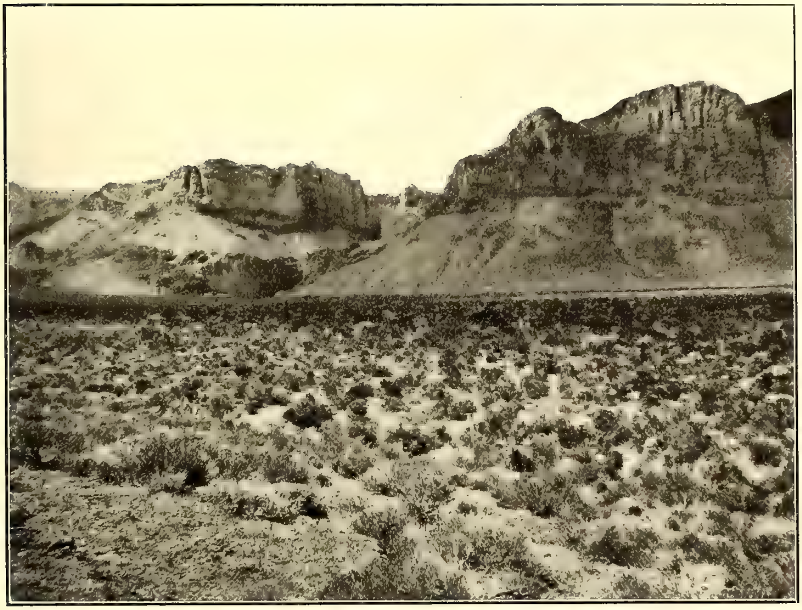


Fig. 1.—Thousand Creek Ridge, and eastern entrance to Thousand Creek Cañon, showing fault scarp and prominent exposures of Cañon Rhyolite.

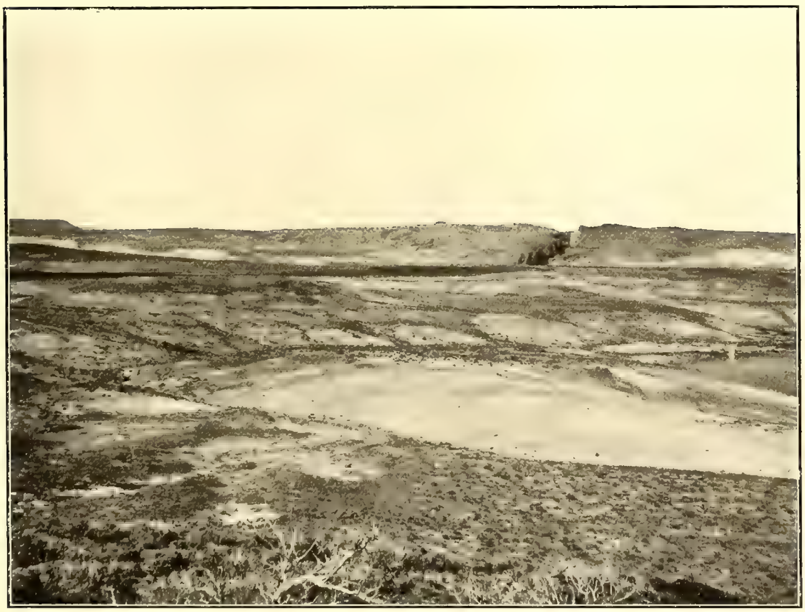


Fig. 2.—Thousand Creek Cañon seen from the western or Virgin Valley side. Thousand Creek Ridge in background composed of Cañon Rhyolite. Virgin Valley Beds in foreground.

Thousand Creek Ridge seen from the north. Eastern entrance to Thousand Creek Cañon opposite the arrow to left of picture. Virgin Valley to right of ridge, Thousand Creek Flats to left.

but are less distinctly folded than the basal rhyolites. The basalt capping is practically horizontal.

Cañon Rhyolite.—In Virgin Valley, and also at Thousand Creek, the formation underlying the mammal beds consists of rhyolitic flows. In Virgin Valley this basal series is folded into a syncline containing the Virgin Valley Beds. The rhyolites are well exposed on the western side of Virgin Valley at Hard Rock Ridge near Virgin Ranch, where they are dipping gently to the northeast beneath the Virgin Valley Beds. These beds form the sharp gorge through which Virgin Creek enters the valley from the southwest. To the east, the rhyolites form Thousand Creek Ridge, which slopes gently to the southwest and drops off precipitously to the east (see pls. 3 and 4, and text fig. 2). Through this ridge the drainage of the valley escapes in a deep, narrow cañon cut by Thousand Creek. At Thousand Creek Cañon the rhyolites are exposed to a thickness of not less than four hundred feet and dip gently toward the southwest, or toward the middle of Virgin Valley.

At the top of the hill above Thousand Creek Cañon, the uppermost beds to the south of the wagon road are practically horizontal, and judged from their position possibly represent a phase of the rhyolite laid down after the earlier portion of the formation had been eroded and deformed. From this upper phase much of the rhyolite occurring as pebbles and boulders in the rhyolitic gravels apparently interbedded with the Virgin Valley Beds (see p. 41), seems to have been derived. The rhyolite flows are accompanied by tuffs, which are exceedingly coarse in places, the fragments of pumice in them being in many cases several inches in diameter.

The precipitous slope on the east side of the rhyolitic outcrop at Thousand Creek Cañon is a fault-scrap, the base of which is covered on the east side by the mammal beds of Thousand Creek. On the eastern side of the Thousand Creek basin the same mammal beds rest upon the rhyolites forming the upper portion of the eruptive series on the northwestern flank of the Pueblo Range.

The rhyolites of Thousand Creek Cañon may be traced around the borders of Virgin Valley to the northwest along the

valley of Beet Creek, and seen from a distance they appear to form the sharp gorge at the upper end of Beet Creek (fig. 3, p. 37).

The rhyolites evidently extend south from Thousand Creek to the valley of Gridley Lake, where Heindl found them exposed on the west side of the valley by a fault running northeast and southwest, in a line nearly continuous with that of the fault west of Mud Lakes to the north. The western flank of Pine Forest Range just to the east of Gridley Lake valley seemed to Heindl to consist of an eruptive series similar to that exposed in the fault-scarp on the west side of the valley.

An outlying mass of rhyolite is also seen in a prominent hill known as Antelope Butte, which rises above the lava-covered mesa south of Virgin Valley (see fig. 4, p. 41).

The rhyolites in these several regions are quite similar petrographically, they are always below the mammal-bearing formations, they have experienced about an equal amount of deformation, and there is evidence indicating that they belong to the series of eruptives flanking the western side of the Pine Forest Range; so that they may all be considered as representing approximately the same horizon. From their occurrence in gorges around the borders of Virgin Valley, these lavas may be known as the Cañon Rhyolite. They are presumably only a portion of the extensive series for which the geographic appellation of Pueblo Range Series is used.

As was shown by Blake[8] the rhyolites of the Pueblo Range are only the uppermost portion of a thick series composed largely of basalts. In his mapping of the formations of southeastern Oregon, Waring[9] has recently shown that the principal series of lavas occurring over this region consists largely of basalts followed in many instances by rhyolites. The rhyolites of the Virgin Valley region are presumably only the upper portion of this extensive formation. As has been stated by both Blake and Waring, there is reason to believe that this series of eruptives is to be correlated with the great lava beds reaching over a very wide extent of territory in the Columbia River region.

[8] Op. cit., p. 214. 1875.

[9] Op. cit. 1909.

As extensive lava formations both older and younger than the Columbia Lava are well known in the great Columbia River area immediately to the north, it is desirable that the eruptive series of southern Oregon should be carefully compared with those of several typical sections where the age and relationships of the lavas have been determined. From the point of view of general geology it is very desirable that an attempt be made to connect the area mapped in southern Oregon with the section of the John Day region, which is the most satisfactory series of formations for correlation purposes that has yet been observed in this region.

With our present knowledge of the eruptive formations of southern Oregon, there is reason for considering the principal lava series, of which the Pueblo Range Series seems to be representative, as presumably, though not certainly, the correlative of the definite horizon of eruptives situated between the John Day and Mascall formations on the John Day River, at Picture Gorge, near Dayville, Oregon. To this phase of the igneous succession the name Columbia Lava has been definitely limited by the writer[10], as it seemed desirable not to discard entirely the name so appropriately suggested by Russell[11] for the great lava flows of the Columbia River region[12].

Virgin Valley Beds.—Resting upon the Cañon Rhyolite in Virgin Valley is a thick sedimentary series, consisting largely of volcanic ash and tuff, which has been designated as the Virgin Valley Beds[13] (see pl. 5; and text fig. 2, p. 30). It is from this formation that the Tertiary mammalian fauna of Virgin Valley is obtained.

The Virgin Valley Beds have been protected by the overlying Mesa Basalt, which now forms extensive table lands on each side of the valley; and in the escarpments bordering the mesas exceptionally good sections are exposed. Although a considerable fauna has been obtained from these beds, vertebrate remains are nowhere abundant in them, and the collections available represent much painstaking effort.

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10 Univ. Calif. Publ. Bull. Dept. Geol., 2, p. 303. 1901.

11 Russell, I. C., U. S. Geol. Surv. Bull. no. 108, p. 20. 1893.

12 This igneous series has also been known as the Columbia River Lava.

13 Merriam, J. C., Science, n.s., 26, 1907, p. 380.

The thickness of the Virgin Valley Beds, measured from the uppermost strata to the floor of the valley, is about 1500 feet. The beds are evidently thinnest around the edge of the valley, and the bottom of the formation is not reached at the point where the measurements were made. Even taking into account a slight dip of the beds from the highest point toward the lowest level, the total thickness may be estimated at over 1500 feet.

Throughout the whole extent of the valley the strata are found to vary only a few degrees from a horizontal position, excepting through landslides. Such variation from the horizontal as is shown expresses a gentle syncline with the depression near the middle of the valley. This is presumably due mainly to a slight deformation which has taken place since the principal accumulation occurred. It may be due in a small part to conformation to the form of the trough in which the beds were laid down.

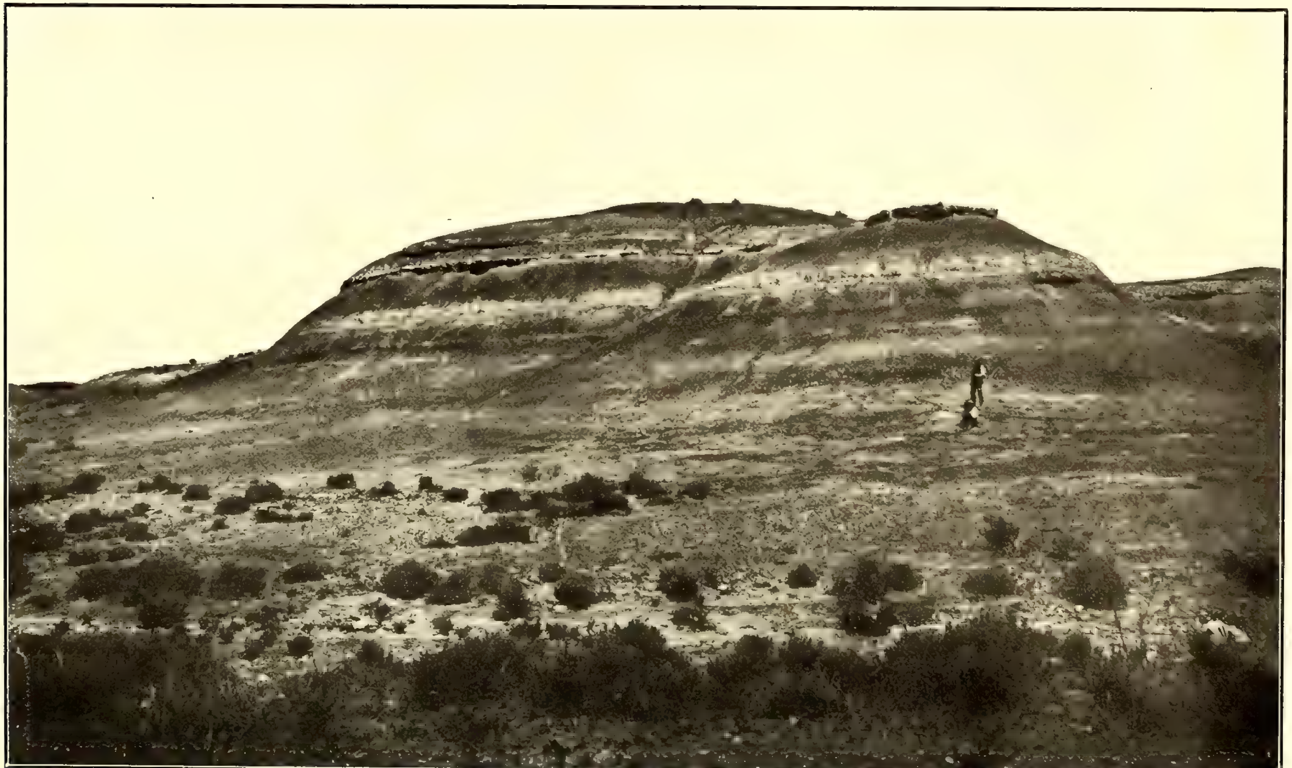
The Virgin Valley Beds are almost entirely made up of volcanic ash and tuff. At several horizons gravel, sand, clay, lignite, and diatomaceous deposits occur, but are of much less volume than the beds of purely volcanic origin.

The lowest strata recognized in the valley are ashes and tuffs dipping gently to the west along the western side of Thousand Creek Ridge (pl. 5). These strata are predominatingly white, but range in color through bright red, purple and green. This phase is overlain commonly by a series of dark red beds which have quite an extent along the stream bed in the northern part of the valley.

The lowest beds of the series rest upon the irregular surface of the Cañon Rhyolite. Such evidence as is available suggests unconformity between the lower Virgin Valley Beds and the Cañon Rhyolite.

The white ashes of the lowest portion of the section have probably accumulated quickly. The dark red horizon presumably represents a period of slower accumulation with extreme oxidation. The mode of accumulation of the lowest beds examined is not strongly suggested by any evidence obtained thus far, but they are not improbably aeolian. The red beds are possibly aeolian.

View of Virgin Valley looking west across the valley of Virgin Creek from the foot of Thousand Creek Ridge. Basal Virgin Valley Beds in foreground. Mesa in background composed of Virgin Valley Beds capped by Mesa Basalt.



Lower Virgin Valley Beds with mammal-bearing strata covered by carbonaceous shales. East side of Virgin Valley.

Carbonaceous shales with thin seams of lignite. Lower phase of Virgin Valley Beds, south side of valley of Beet Creek.

The section of the formation immediately above the dark red horizon is distinguished by a brownish-yellow coloration over a considerable part of the valley. The same general horizon is apparently represented by a grayish or buff phase in many places.

In that portion of the section above the red beds, at some localities in the yellow phase and at others either below or above it, there are considerable thicknesses of thinly-bedded, highly carbonaceous shales which may contain numerous lignitic layers (pls. 6 and 7). The shales are largely clay and ash, but may be diatomaceous. The lignitic seams are very numerous in some of the sections, as on the south side of the valley of Beet Creek. They have usually a thickness of only an inch or two. Prospecting for coal has been carried on in this portion of the series but no deposits of economic value have yet been discovered.

A number of fossil leaves were obtained in the section on Beet Creek. It has been found very difficult to transport specimens owing to the friable nature of the rock, and only a few species have been obtained for study.

At one locality of the middle beds in Virgin Valley opal specimens of some commercial value are found. The opals occur largely in cracks or cavities in the typical fossil-bearing beds of this horizon.

The deposits of that portion of the Virgin Valley represented by the yellow beds and the carbonaceous strata were certainly in part laid down in water. The diatomaceous beds are of aqueous origin, and some of the gray clayey strata which are found to contain fish-bones in considerable numbers must also have been formed in water. The shales with numerous lignitic seams are evidently swamp or lake deposits in a large part.

That portion of the Virgin Valley Beds above the yellow and the carbonaceous phase of the formation constitutes the largest part of the series of beds exposed. It is made up almost entirely of white to buff or cream-colored ash and tuff. Some strata are almost pure, sharp-edged ash which has been but little worked over. In other beds, the glass is much decomposed and the material has apparently been worked over considerably. There

are in this portion of the section a number of beds of gravel and boulders which are evidently of fluviatile origin, but the impression given by this section as a whole is that it is largely of aeolian origin. This suggestion is also supported by the nature of the fossil remains in these beds, which are those of land forms. This does not preclude the possibility that some of the strata accumulated in temporary lakes.

During the deposition of the Virgin Valley Beds the conditions of accumulation were apparently much as those at the present time in most of the large valleys of the Nevada or eastern Oregon region. The Cañon Rhyolite evidently formed the rim of the valley, while the sediments laid down in it were spread out to form a broad and nearly level floor. Whether the conditions were such as to cause sedimentation in water or in air, the evenness of the stratification remained much the same.

As suggested under the discussion of the later history of this region (see p. 43) there is reason for believing that a considerable thickness of rhyolitic gravels resting unconformably upon the middle beds of the Virgin Valley section in the angle between the valleys of Virgin Creek and Beet Creek (pl. 8), represents deposition within the Virgin Valley epoch. Whether this unconformity exhibited here is general throughout the Virgin Valley section, or whether it is a purely local feature is not known. If it should be found to represent a widespread condition of erosion, it would be necessary to divide the Virgin Valley section into an upper and a lower division. In this case, the name Virgin Valley Series may be applied to the whole group of beds between the Cañon Rhyolite and the Mesa Basalt. The beds below the unconformity would then be known as the Lower Virgin Valley Beds, those above the unconformity the Upper Virgin Valley Beds.

Mesa Basalt.—Where they are not uncovered by erosion, the Virgin Valley Beds are capped by an extensive sheet of olivine basalt of a doleritic facies. This capping forms the "rim rock" of the great mesas on both sides of the valley of Virgin Creek and may be known as the Mesa Basalt (see pls. 9 and 10, text fig. 2, p. 30, and text fig. 3). So far as observed, the lava sheet is not distinctly unconformable upon the underlying

Middle division of Virgin Valley Beds covered unconformably by rhyolitic gravels. South side of valley of Beet Creek.

Upper Virgin Valley Beds covered by Mesa Basalt. Northwest side of valley of Virgin Creek, exposure near A of A-B line shown on plate 2.

beds. The table-lands covered with this lava capping are known to extend for a distance of fifteen or twenty miles north and south. As seen from a commanding point above its level, the table-land appears to have an extent several times the length of the section in which the basalt capping has actually been traced, and the presumption is that this flow reaches over a territory much larger than that personally visited. The surface of the basalt cap, and of the mesas in general, is normally

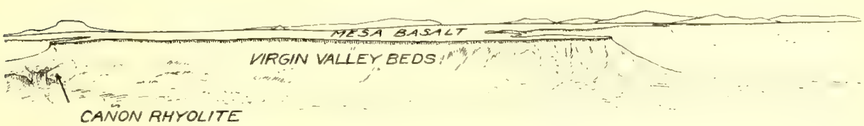


Fig. 3.—View of the mesa north of Beet Creek. See also plates 2 and 10.

nearly level, or with only slight undulations. Several faults of considerable magnitude have developed in the mesa to the northeast of Virgin Valley in the movement of large crustal blocks in comparatively recent time.

To one traveling over the mesas, the surface of the table presents a most unusual spectacle. The lava is only partly covered by irregular patches of soil in which no plants larger than sagebushes have developed. The evenness of the surface and the unvarying nature of the long stretches of sagebrush and lava blocks are such as to make a judgment of distance most difficult. Above the surface of the lava there rise here and there a few prominent points (see pl. 10), as Antelope Butte (fig. 4, p. 41) situated on the mesa south of Virgin Valley. This point consists of a dome of rhyolite which projects as an island rising three hundred feet above the level surface of the basalt flow.

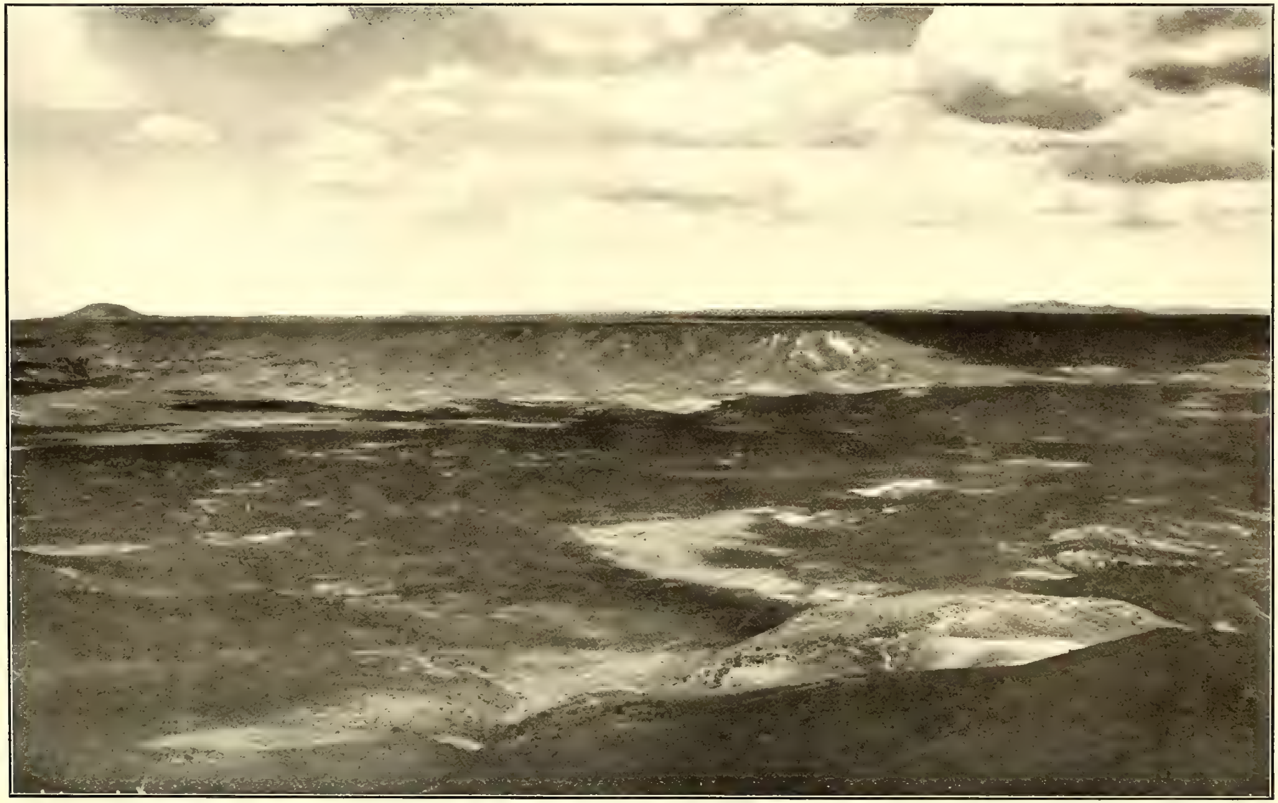
The basalt sheet is near twenty-five feet in thickness over the region where it has been examined, and consists of several fairly distinct layers. The separate beds observed may not be persistent, and may be nothing more than local advances of a single flow. The uniformity in thickness is quite remarkable, and evidently indicates that the lava was poured out on a nearly even plain. Though the dissection of the mesas by erosion

has exposed splendid sections of the region formerly covered by the basalt, no dikes or fissures have been observed through which this lava has come to the surface. Such sources may, however, appear in localities not yet visited. The extent of this flow appears rather remarkable when considered in relation to its thinness. It is difficult to understand how a flow could extend itself so broadly without heaping up more than is indicated in this section.

Taking into consideration the thinness of the flow and the evenness of the floor upon which the Mesa Basalt was laid down, the present aspect of the table-lands surrounding Virgin Valley may be considered as closely representing the nature of the topography of this region during the latter part of the epoch of deposition of the Virgin Valley Beds. If the lava sheet were removed, the sedimentary beds below would form a nearly level plain reaching well up on the side of the range to the south. Many of the salient features of the topography which existed in early Virgin Valley time would be completely buried, while a few of the highest points would project as islands rising sharply above the surrounding ash accumulation.

History Subsequent to Outpouring of Mesa Basalt.—No accumulation of sediment has been observed to rest upon the Mesa Basalt. Though such formations may possibly exist in localities that were not visited, the impression received in a general survey of the table-land region is that the basalt sheet was the last deposit laid down in the region anterior to the events that initiated the cycle of erosion during which the present valley was excavated.

Movements following the outpouring of the basalt sheet are evidenced in the presence of a sharply-marked fault along the line of the scarp following the east face of Thousand Creek Ridge. The basalt cap to the north of Thousand Creek Cañon is sharply cut off along the extension of the axis of the ridge, the mesa on the east side of the jog dropping a little over four hundred feet below the level of the mesa to the west. This movement is a late phase of the adjustment of crustal blocks which evidently began moving before the deposition of the Virgin Valley Beds. It is not improbable that a small amount



View of mesa north of valley of Beet Creek. Table land capped by Mesa Basalt resting upon Virgin Valley Beds. Cañon Rhyolite underlying Virgin Valley Beds in middle distance to left of picture. See also text-figure 3.

of movement occurred along this line during Virgin Valley time. The level of the region to the west of the fault-line must have been somewhat higher than that of the country to the east after the basalt outflow in order to permit the establishment of the present drainage system, which flows toward the east across Thousand Creek Ridge.

The drainage system of Virgin Valley as it now appears is a very interesting feature of the region, as it pursues its course apparently without respect to very prominent barriers (see pl. 2). To the north, west, and east of the valley the streams cut narrow cañons through very hard ridges of the older rhyolitic rocks; while the stream-beds in the valley proper are broad, and in some cases widen out into marshy belts. The small stream of Thousand Creek, formed by the union of Virgin and Beet creeks, leaves the broad, open valley to cut straight into the hard rhyolite of Thousand Creek Ridge, through which it passes in a very narrow cañon (pls. 3 and 4). It is evident that the barriers crossed by the present drainage were passed in the process of cutting through the Virgin Valley Beds and into the buried ridges of the older formation. The general progress of cañon cutting may have been retarded considerably at times by the nature of the opposing barriers and movements along the fault-line crossing the stream at the mouth of Thousand Creek Cañon possibly retarded it still farther.

During the process of excavation of Virgin Valley there appear to have been several resting stages of which some record is left in terraces. At least two levels of terracing seem to be indicated on the slopes of the valley. Both represent levels of relatively slow accumulation of alluvial fans, which have been followed by periods of cutting in which the ends of the older fans have been sharply truncated. The levels of these terraces are about twenty feet and forty feet above the present floor of the valley.

In the course of excavation of the valley, numerous landslides have evidently been an important feature in the movement of material from the walls of the bordering table-lands. On both sides of Virgin Creek numerous large blocks of the mesa with the basalt capping almost intact are seen in various

positions on the slope below the lava cap (pl. 11, fig. 1). On the edge of the mesa, blocks half a mile or more in extent may be seen in the first stages of movement. In the lower part of the valley near the union of Virgin Creek and Beet Creek a long series of lava-capped hills reaches for a distance of at least two miles from the mesa down to the present stream-bed (see pl. 5). The strata in these hills are frequently sharply inclined, usually with the dip toward the mesa (pl. 11, fig. 2). The lava capping consists of material identical with that in the basalt cap of the mesa.

The separation of large blocks from the valley wall is evidently due in a considerable measure simply to the cutting of small streams, the basalt cap having protected the underlying mass until the wall was cut down to a very steep slope. The breaking away of blocks of large size is evidently assisted greatly by seepage developed through breaks in the lava cap. The presence of such channels of seepage on the mesas both north and south of Virgin Valley is evidently indicated by a series of peculiar lakes scattered over the table-lands. The lake basins, in some cases at least a mile in diameter, are situated on the level lava tables (fig. 4). They are usually approximately circular, with steep marginal walls formed by the basalt. Though the lava cap has disappeared over the area of the lake basins, there is no lateral outlet for wash. The only supposition on which we can account for the presence of these depressions seems to be that they have been formed by the sinking of the lake floor. This would most probably be caused by lines of seepage causing readjustment of the ash strata below, partly through the condensing effect of water on the beds of loose ash. Seepage of this character would also tend to separate large blocks from the main valley wall. Depressed areas, developed some distance away from the margin of the mesa, when reached by recession of the valley wall would presumably tend to move as large slides.

In the movement of the numerous blocks which have been detached as slides from the mesa walls it is not improbable that earthquake shocks have played a part of some importance. In the fault movement which caused the four hundred foot displace-

Fig. 1.—East end of mesa between valleys of Virgin Creek and Beet Creek, showing large blocks recently moved down from top of mesa.

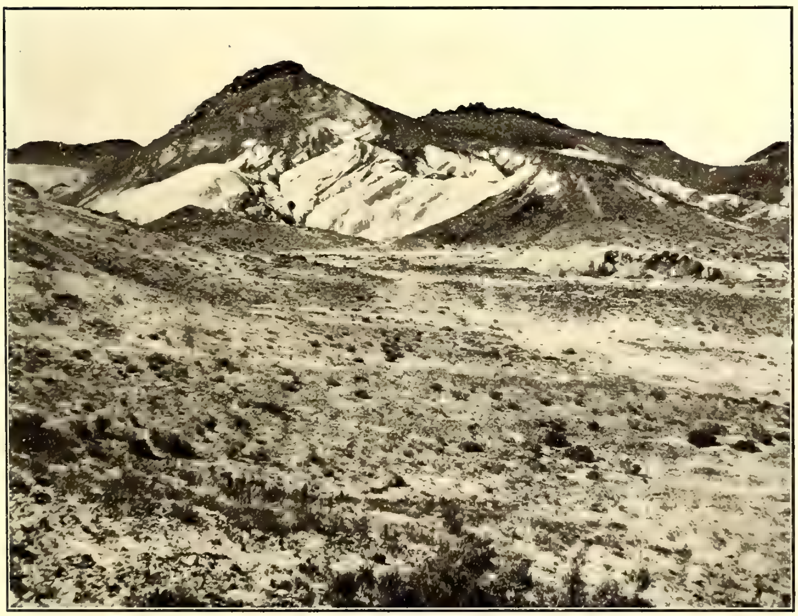


Fig. 2.—Much disturbed masses of Virgin Valley Beds with lava capping. Presumably representing old slides. Northwest side of valley of Virgin Creek.

ment along the east side of Thousand Creek Ridge in post-Mesa Basalt time, earthquakes of considerable violence probably occurred.

Suggestions of a stage during which considerable volumes of sediment may have accumulated in the valley before it had

Fig. 4.—A portion of the mesa south of Virgin Valley. Antelope Butte, a prominent dome of rhyolite in the background, rises above the level floor of basalt. The circular lake in the foreground is surrounded by steep walls of basalt.

attained as much as one-half of its present depth are offered by a bed of gravel and boulders which covers the top of a prominent ridge in the angle between the drainage of Virgin Creek and Beet Creek (pl. 8). At this point the top of the spur running out from the sharp eastern point of the mesa is covered with at least fifty feet of coarse gravel and boulders. Farther east Mr. Heindl measured a section of this gravel one hundred and twenty feet thick. At some points near the east end of the ridge these gravels are interbedded with strata which appear like a part of the Virgin Valley Formation. Along a large portion of the north side of this ridge the contact between the gravel and the underlying Virgin Valley Beds is

very clearly exposed, and a strongly marked angular unconformity of at least ten degrees variation in dip is shown. At some points the underlying strata are considerably contorted. The sharp minor folds might possibly be due to local slipping of soft strata below a contact with the gravels. The angular unconformity shown in a long exposure of the cliff can be interpreted only as the result of erosion preceding the deposition of the gravels.

The gravel deposits resting upon the eroded Virgin Valley Beds consist almost entirely of large, well-rounded rhyolite fragments ranging up to more than two feet in diameter. The rhyolite closely resembles some of the flows in the formation forming the rim of Virgin Valley. A very few well-rounded pebbles of basaltic lava were obtained. Mr. Heindl, who has examined this basalt, finds it very different from the Mesa Basalt. While basaltic pebbles are rare in the mass of these gravels, large blocks from the basalt capping of the mesa near by are found resting on the top of the gravel beds.

The unconformity of the rhyolitic gravels on the Virgin Valley Beds might be interpreted as meaning that it represents a stage of accumulation in a valley cut after the period of the Mesa Basalt flow. On the other hand it is noted that basaltic pebbles are quite rare in the rhyolitic gravels, while large masses of basalt from the edge of the mesa are found resting upon the top of these gravels. The edge of the basalt covering the mesa is near at hand, while the flows from which the rhyolite pebbles have been largely derived are much farther removed. It is moreover not probable that the few basaltic pebbles in the gravel are derived from the Mesa Basalt, and basaltic flows are presumably associated with the rhyolites below the Virgin Valley Beds. This evidence seems to show that the accumulation of the gravels occurred before the Mesa Basalt flow, otherwise there should be at least as large a percentage of fragments derived from the mesa cap as we find in other deposits known to have formed during the cutting of the present cañon.

The suggestion that the rhyolitic gravels accumulated at an early resting stage in the cutting of the present valley is probably further negatived by the presence of numerous large

land-slides between these gravel beds and the present bed of Virgin Creek. If at an early stage in its history, the main stream had occupied the position in which the gravels are now situated, it must since then have cut to the south and east across the present valley. If this had occurred, the numerous remnants of slides from the mesa wall, which lie between the rhyolitic gravels and the present stream would necessarily have been removed. As a possible alternative the slides might be supposed to have travelled across the rhyolitic gravels and down into their present positions. This is certainly a violent assumption, as the slides are now separated from the mesa by one or two miles of relatively flat territory.

The weight of evidence seems to indicate that the rhyolitic gravels were deposited after a short stage of erosion which occurred during the general period of sedimentation characterized as the Virgin Valley epoch. This theory receives support from an observation by Mr. Furlong, who has noted the occurrence of beds of gravel and boulders in the face of some of the exposures of the Virgin Valley Beds one or two miles north of the main occurrence of the gravels. The exposures observed by Furlong were at about the same general level below the mesa as the main outcrop of the rhyolitic gravels. The gravel and boulders were interbedded with the ash strata, and as nearly as the writer can judge from Furlong's description they were of much the same nature as the main rhyolitic gravel outcrops.

THOUSAND CREEK BEDS.

In the region immediately to the east of Thousand Creek Ridge there are extensive exposures of mammal-bearing beds bordering the basin known as Thousand Creek Flats. Large outcrops of these beds are present along the eastern base of Thousand Creek Ridge, and similar beds reach for many miles north from Thousand Creek. A long, narrow, lava-capped mesa known as Railroad Ridge extending nearly north and south for six or seven miles into the Thousand Creek basin is composed of similar beds (pl. 2 and text fig. 5). To the north of the Thousand Creek basin, near a prominent point known as Oregon End, the sedimentary series of Thousand Creek Flats apparently

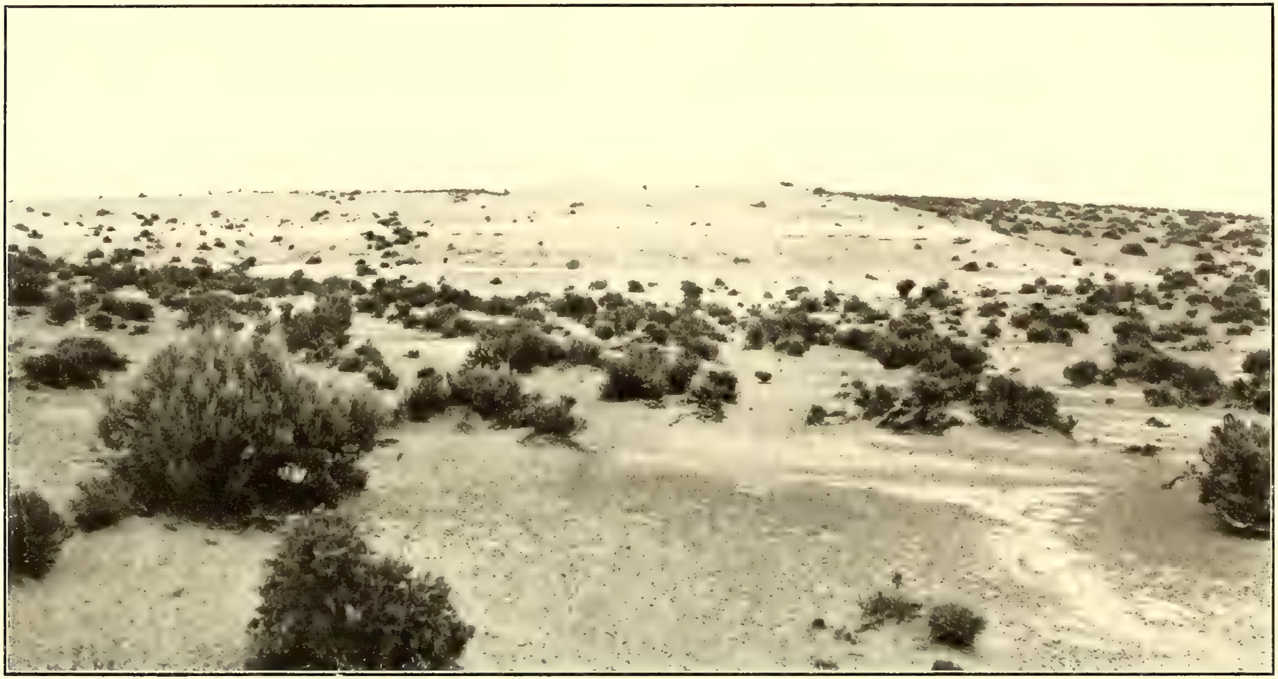
extends under a mesa which corresponds in general to the table-lands in the Virgin Valley region. The capping of this mesa is similar to the Mesa Basalt in Virgin Valley. On the northwestern border of the basin large outcrops of ashy beds, apparently representing the later Virgin Valley Beds, are visible beneath the basalt cap. To the east of Thousand Creek Flats the mammal beds come in contact with the upper portion of the Pueblo Range Series. The mammal beds here seem to extend

Fig. 5.—Section along the C-D line on plate 2, showing section from Thousand Creek Ridge to Railroad Ridge.

in nearly horizontal position over to the contact with the rather steeply inclined upper beds of the Pueblo Range Series, so that the relation of the two groups of beds is apparently one of unconformity.

The principal exposures near Thousand Creek consist of tufaceous beds, ashes, and sands, ranging from white to red and dark brown. Many of the strata presumably represent ancient soil accumulations much like that covering the floor of the valley at the present time. Distinctly sandy layers appear a short distance below the top of the section at the northern end of the basin, and also in the beds at the southern extremity near Thousand Creek Ridge. A layer of white to gray ash, one to two feet thick, is exposed low in the section near Thousand Creek Ridge, and one is also seen in the beds at the northern end of the basin. The two may represent the same horizon, but they have not been traced through the series of exposures. Beds of gravel of considerable extent are also present. In some instances the gravels may represent terrace deposits of more recent age than the principal exposures of mammal beds in the basin.

Both the southern and northern exposures in Thousand Creek basin are truncated by a terrace or mesa having approximately the same level as the top of Railroad Ridge. An exception to this is seen in a prominent hill which rises above this table and above Railroad Ridge in the northern exposures.



Exposure of Thousand Creek Beds. Northern portion of Thousand Creek basin.

Around the borders of Thousand Creek Flats there are several distinct terraces which are much below the level of the Railroad Ridge mesa, and are evidently of late Pleistocene age. They are shown in the broad flats situated just south of Railroad Ridge. This bench is about sixty feet above the present level of the stream bed and is apparently underlaid in a large part by undisturbed mammal beds.

The Thousand Creek Beds are in general approximately horizontal, or dip slightly toward the southwest; that is, toward Thousand Creek Ridge. In the exposures at the northern end of the section the strata are noticeably tilted, and the dip does not appear to be conformable with the plane of the terrace or mesa above.

The nature of the beds exposed in Thousand Creek basin is in a general way similar to that of the sedimentary formation in Virgin Valley, though it does not repeat the characters of any particular portion of the Virgin Valley section. Possibly more sandy strata have been seen in the Thousand Creek section than were actually noted in the beds in Virgin Valley. If the Thousand Creek exposures represent the same epoch of deposition as those of Virgin Valley, it is evident from the contained fauna that they must correspond to the upper portion of the Virgin Valley Beds rather than to the lower portion of that section.

So far as known, the mammal collections from the beds around Thousand Creek Flats all seem to represent one fauna, with the possible exception of a few remains obtained from deposits which occur on some of the lower terrace levels in the valley. The few specimens obtained from the terraces seem to represent a member of the horse group very near in its characters to the Quaternary genus *Equus*, whereas the other horse remains from the Thousand Creek exposures certainly represent an older group. As the remains from the terraces are fragmentary, it is possible that they do not actually represent forms very different from the other specimens, which are better preserved. It is also not at all certain that the deposits below the apparent terrace levels are distinct from the other Thousand Creek exposures.

With the exception of the possible Quaternary remains from

Thousand Creek, the mammalian fauna which is found widely spread in the exposures of this region represents a stage of the late Tertiary, but apparently not the very latest portion of the Tertiary.

In comparing the fauna of Thousand Creek with that of the Virgin Valley Beds, there are found to be a few species common to the two; but by far the greater number of the species, and even of the genera, are different. In most respects in which it is possible to make a comparison, the Thousand Creek forms are more advanced or more specialized than those of Virgin Valley. Judging by the fact that a few species are common to the two faunas, there is reason for considering them as not widely separated in time. On the other hand, it is difficult to place them in the same epoch, and it is evident that the Thousand Creek fauna is the later one.

A summing up of the evidence presented by the Thousand Creek fauna with reference to the age in relation to that of the other formations of this region shows the following points: (1) The Thousand Creek fauna is of late Tertiary age; (2) It is later than the fauna obtained from the lower and middle Virgin Valley Beds; (3) It was not widely separated in time from the known Virgin Valley fauna, as there are a few mammalian species common to the two.

Although resembling the Virgin Valley Beds in a general way, it is evident from their contained fauna that the wide extent of exposures in which collections of fossil mammals have been made in the Thousand Creek region cannot represent the lower or middle portion of the section in Virgin Valley, in which the typical Virgin Valley fauna has been found. Unfortunately almost nothing is known of the fauna from the uppermost portion of the Virgin Valley section, possibly because the steep exposures immediately below the basaltic capping present a collecting area relatively much smaller than that representing the lower horizons. It is therefore necessary to reckon with the possibility that the exposures at Thousand Creek represent the upper portion of the Virgin Valley section.

If the Thousand Creek exposures be held to represent the uppermost portion of the Virgin Valley section, the present

position of the beds in the western part of the Thousand Creek region could be accounted for only on the assumption of very extensive faulting along Thousand Creek Ridge. The fossiliferous beds immediately east of this ridge are now at least a thousand feet lower than the uppermost beds in Virgin Valley, while the drop of the mesa cap east of the fault-line along Thousand Creek Ridge to the north amounts only to a little more than four hundred feet, which is not sufficient to account for more than half of the difference in position, even when original slope of the land and possible recent tilting of the whole region to the east are considered.

The Railroad Ridge mesa, which contains some of the important deposits of the Thousand Creek region, is capped with a basaltic lava which is considered by Professor G. D. Louderback and Mr. E. L. Ickes, who have examined it, as representing the same type of rock as that in the Mesa Basalt. The capping of Railroad Ridge is about four hundred feet lower than that portion of the main mesa to the north, which has been faulted down to the east of the Thousand Creek Ridge fault. There is therefore some reason for considering that Railroad Ridge, and presumably the mammal beds exposed near it, belong to a block which has dropped very far below its original level.

Mr. Heindl, who has examined the section of Railroad Ridge (see fig. 5, p. 44), finds the uppermost beds composed of very coarse gravels consisting of pebbles of rhyolite, basalt and obsidian, and has suggested that this ridge represents an ancient lava-filled river bed. The course of the ridge runs out from the vicinity of the existing cañon of Thousand Creek, and would suggest a drainage passing near the line of the existing cañon (see pl. 2). If the river bed was present immediately before the outpouring of the Mesa Basalt and before the later movements along the Thousand Creek fault, this portion of the lava flow might be presumed to have resisted erosion longer than the adjoining portions owing to the original greater thickness of the lava over the channel of the old stream.

The idea that the Railroad Ridge lava represents the basalt filling of an old river bed also suggests that the Thousand Creek Beds might have accumulated in part from erosion of the western

fault block previous to the outpouring of the Mesa Basalt. If extensive movement occurred along the Thousand Creek fault line before the outflow of the Mesa Basalt, accumulation may have taken place to the east of this line. During the time of such accumulation probably no deposits would be formed over the Virgin Valley region. Unless the whole region were reduced to the same level following such differential movement, one would expect to find the Mesa Basalt accumulating to much greater thickness east of the fault line, which is not clearly shown. A movement in pre-Mesa Basalt time, such as is suggested here, would presumably not result in more than a relative thickening of the beds to the east of the fault line, and possibly in a temporary interruption of sedimentation over the block west of the fault line.

Another possible explanation of the Railroad Ridge gravels, and of the Thousand Creek Beds in part or as a whole, is that they have been derived from the wash of Thousand Creek or other similar streams during the cutting of Virgin Valley. As a rough estimate, we may consider that at least ten cubic miles of rock have been carried out of Virgin Valley since the initiation of the cutting of the present valley. As nearly as one may judge, the distance to which this material could have been carried was short, and it could have been deposited over only a small area. It is therefore not improbable that some part of this material may have been deposited on the east side of Thousand Creek Ridge, particularly after the faulting movements occurred along the line of this ridge.

According to the hypothesis just suggested, it would be necessary to consider either that the Thousand Creek Beds have been lowered by faulting since their deposition, or that they were accumulated very late in the history of the cutting of Virgin Valley. The beds forming Railroad Ridge are now far below the top of the mesa in Virgin Valley, and we can hardly imagine them as derived from the first sediment washed out in the cutting of the uppermost strata of the Virgin Valley Beds a few miles away and deposited in their present position. Without considering that differential movement has changed the position of these beds in relation to the Virgin Valley Beds since their

deposition, it would be necessary to suppose the Thousand Creek Beds formed from sediment obtained during the cutting of the lower or later portion of Virgin Valley.

The possibilities as to age of the Thousand Creek Beds with relation to the Virgin Valley Beds appear to be as follows: (1) They represent a portion of the Virgin Valley Beds faulted down into their present position. (2) They are younger than the Virgin Valley Beds, but older than the Mesa Basalt, and have been moved down by faulting. (3) They represent an accumulation formed of the *older* wash derived from the post-Mesa Basalt erosion of the existing valleys of Virgin Creek and Beet Creek, or other similar drainage, and have since their accumulation been dropped by faulting. (4) They represent an accumulation of sediment laid down during the period of erosion of the lower or *younger* portions of these valleys. (5) They are not a stratigraphic unit, and may be partly of the age of the Virgin Valley Beds and partly later.

Without more detailed geologic information than it has been possible to obtain, it is not entirely clear as to which of these possibilities corresponds to the actual history.

The first possibility has much in its favor, *viz.*, that the Thousand Creek Beds represent a series of deposits which are comparable to the late Virgin Valley Beds and have been faulted down to their present position.

The second case suggests a situation which is a possibility, though the evidence does not seem to indicate definitely that this has been the mode of accumulation of these beds.

According to the third and fourth possibilities, *viz.*, that the Thousand Creek Beds represent an accumulation of wash carried out in the excavation of Virgin Valley and other valleys of approximately the same age, it must be presumed that the beginning excavation of Virgin Valley occurred a considerable time before the close of the Tertiary, as the Thousand Creek fauna antedates the end of the Tertiary. It would then be necessary to consider that the comparatively thin sheet of Mesa Basalt has been able to protect the Virgin Valley Beds beneath it from erosion through the whole of the Pleistocene and a part of Pliocene time, unless some later formation has in turn pro-

tected the Mesa Basalt. It seems improbable that the Mesa Basalt has been covered by considerable deposits of any kind, as the large level stretches now exposed appear to be entirely bare.

There is strong evidence against the suggestion that the Thousand Creek Beds represent an accumulation of the latest wash from Thousand Creek and other similar drainage, as this would increase the length of the period back to the initiation of the first cutting through the Mesa Basalt. The strongest argument in favor of relatively late age of the Thousand Creek Beds is obtained by Heindl's study of the Railroad Ridge lava, and by his discovery of a basalt pebble in the gravel immediately under the lava. The basalt pebble from the gravels below the lava is considerably decomposed, but seems to be rather nearer the type of the Mesa Basalt than it is to that of the older Pueblo Range lavas. Heindl has also called attention to the fact that the Railroad Ridge lava is not broken up as it might be if it were a block which had been dropped a considerable distance. In the absence of well preserved material, the basalt pebble from below the lava is hardly sufficient evidence to prove that the Railroad Ridge lava is a flow of later age than the Mesa Basalt. The lack of disturbance of the Railroad Ridge lava does not necessarily indicate that this block has not been moved, though minor disturbance might naturally be expected.

Judging from the evidence of the fauna, it seems probable that the Thousand Creek exposures represent in the main a single period of deposition. Upon the lower terraces bordering the valley there may be Pleistocene deposits with a fauna containing *Equus*. Such deposits, if they occur, are apparently not thick, and their presence would hardly confuse the problem as to the age of the great extent of exposures with a late Tertiary fauna.

It is very desirable that more evidence be obtained relative to the purely geologic history of the beds at Thousand Creek. A determination of the exact geologic position of these beds may depend finally upon a study of the fauna, but from the standpoint of the palaeontologist it is most desirable to have the evidence of sequence of faunas based upon stratigraphic succession.

HIGH ROCK CAÑON EXPOSURES.

About thirty miles southwest of Virgin Valley a number of exposures were found to contain a fauna similar to that of the Virgin Valley Beds. The localities at which collections were made are near High Rock Cañon and Little High Rock Cañon (see pl. 1).

The beds in which the mammalian remains were obtained consist of ashy or tufaceous materials resembling some of the exposures in Virgin Valley. The region bordering the valley in which the mammal beds appear is largely lava-covered, and according to Heindl and Furlong the fossil beds appear to dip under the lavas at some localities. Whether the apparent position of the lava over the mammal beds is an original stratigraphic relation is uncertain, as there is considerable faulting in this region. The nature of the lavas here is not certainly known, but a rhyolite seems to form the greater part of the outcrops. A further study of this region is desirable.

During the period in which the Virgin Valley Beds were being deposited there was probably more or less accumulation of similar materials over a wide area in this region. The deposits laid down at this time may have formed extensive continuous sheets in some localities. In this particular place accumulation may have taken place in small separated basins formed through faulting.

PHYSICAL CONDITIONS OBTAINING DURING DEPOSITION OF VIRGIN VALLEY AND THOUSAND CREEK BEDS.

The sedimentary deposits, and the fossil remains which have been found in them at Virgin Valley, show that there was some variation in the physical conditions obtaining in this region in late Tertiary time. During the deposition of a portion of the lower beds in Virgin Valley, swampy or moist ground covered a considerable area, and thin lignitic deposits were formed. Particularly during the deposition of the middle portion of the Virgin Valley Beds, there was a partial forestation of the region, as is evidenced by the abundant petrified remains of large trees preserved in these strata. The mammalian fauna

of the Virgin Valley Beds is in general that of a fairly open country.

In the Thousand Creek Beds, representing a later period than the lower portion of the Virgin Valley section, no evidence of lignitic deposits like those of Virgin Valley has been noted. During this epoch the mammalian fauna included many forms which are commonly found on open plains, as antelopes, camels, horses, and rhinoceroses. It is probable that at this time the conditions here were not greatly different from those obtaining in the less arid areas of the northern part of the Great Basin at the present day.

SUMMARY OF PRINCIPAL EVENTS IN THE GEOLOGIC HISTORY OF THE VIRGIN VALLEY REGION.

Following is the succession of principal events in the depositional and erosional history of the Virgin Valley region. The Thousand Creek Beds have been omitted from this scheme, as their position in the column is largely determined by palaeontologic data which are naturally presented in the second part of this paper. As the geologic studies presented here have been undertaken for the purpose of assisting in an understanding of the history of mammalian life, in the following table the evidence used is that obtained without the aid of palaeontology. In the general discussion of age and relationships of the faunas, which will appear in Part II of this paper, the evidence of age has been assembled from all sources.

Terrace formations.	Terracing, and accumulation of gravels in later history of Virgin Valley.
Cañon cutting	Cutting of Virgin Valley to depth of nearly 1500 ft.
Mesa Basalt	Outpouring of wide-spread but thin sheet of basalt
Virgin Valley Beds	Accumulation of at least 1500 ft. of ash, tuff, and carbonaceous shale.
Epoch of erosion	Erosion probably accompanied by faulting
Pueblo Range Series	Accumulation of much more than 1000 ft. of basalt, tuff, and rhyolite. Rhyolite following basalt.

With reference to the age or correlation of the formations included in this list, the following opinions have been expressed:

Virgin Valley Beds	Merriam.[14] 1907. Miocene; upper beds not older than Mascall Beds of John Day region; lower beds Miocene, but may represent a different phase. Gidley.[15] 1908. Middle or lower Miocene; not newer, and may be older than Mascall Beds.
Pueblo Range Series	Blake.[16] 1875. Early Miocene. Merriam.[17] 1907. Cañon Rhyolite of Virgin Valley superficially resembles a part of the Clarno Eocene series of the John Day region. Waring.[18] 1909. The lava series forming a large part of Steens Mountain is correlated by Waring with the Columbia River basalt (Miocene). The Steens Mountain lavas are presumably the same as the Pueblo Range Series.

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[14] Op. cit., p. 382. 1907.

[15] Op. cit., p. 242. 1908.

[16] Op. cit., p. 212. 1875.

[17] Op. cit., p. 381. 1907.

[18] Op. cit., p. 21. 1909.

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GEOLOGY

Vol. 6, No. 3, pp. 55-78, Pls. 13-18 Issued February 18, 1911

THE GEOLOGY OF THE SARGENT OIL FIELD

BY

WILLIAM F. JONES

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CONTENTS.

INTRODUCTION.

The area to be discussed in this paper embraces the southeastern end of the Santa Cruz Mountains where they merge into the Santa Clara and San Benito valleys. The area covered by the map embraces the southeastern corner of Santa Cruz County, part of Santa Clara County, and a narrow strip of San Benito County south of the Pajaro River.

The selection of this region for study was influenced by the many facilities offered by Mr. J. C. Kemp van Ee, to whom the writer is much indebted. Through the kindness of the Watsonville Oil Company a topographic map was procured which served as a base for detailed field work. Reconnaissance work was carried on outside the mapped area when necessary. Some of the facts brought out by the field work are thought to be of sufficient importance and interest to be worthy of publication.

The writer wishes to express his thanks to Mr. J. C. Kemp van Ee for his interest and aid in the work, to the Watsonville Oil Company for the use of the unusually good topographic map and the logs of the oil wells on the Sargent ranch, to Professor Andrew C. Lawson for very material aid in the field and in the laboratory, and to Mr. C. A. Mitchell, foreman of the Watsonville Oil Company's wells, for his coöperation.

PHYSIOGRAPHIC FEATURES.

The general physiographic features of the Santa Cruz Mountains are well known. The most striking feature, perhaps, is the dominant northwest-southeast trend of the ridges and valleys. The only exception to this generality is the valley of the Pajaro River which trends almost due east and west in

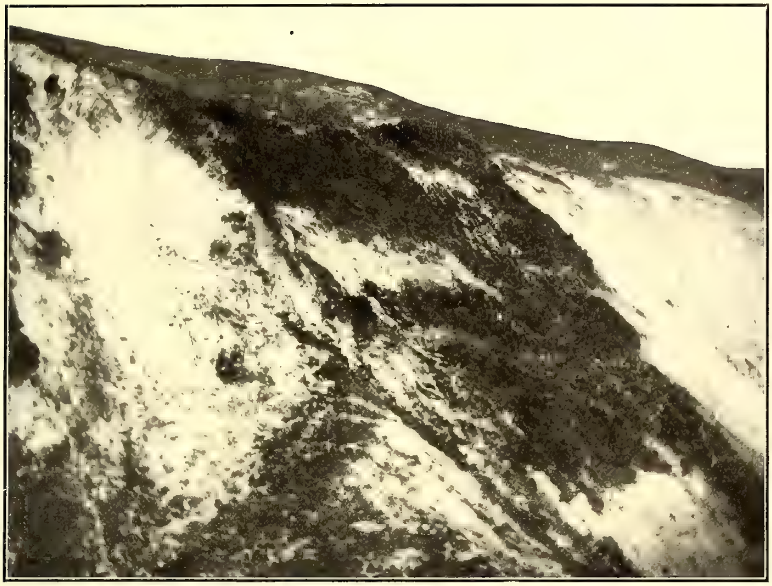

Fig. 1.—Steep slopes of Monterey shale on south side of Shale Mountain. Slides due to earthquake of 1906.

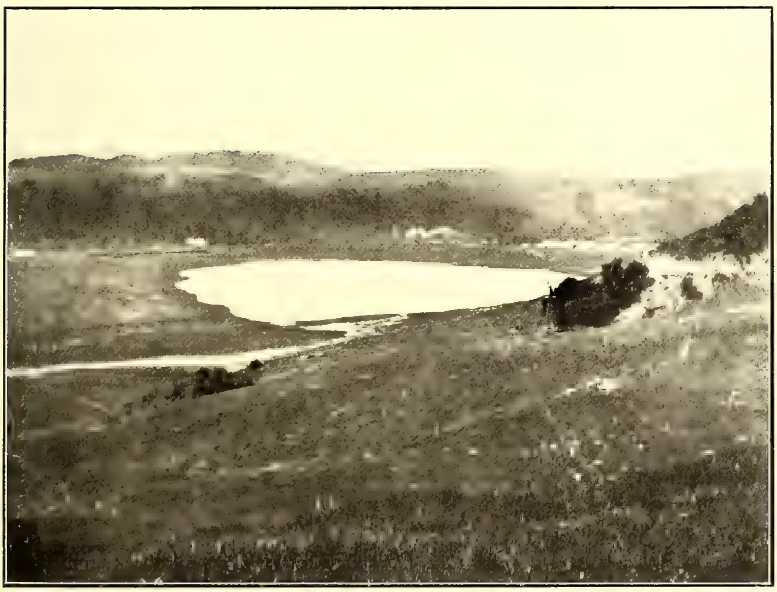

Fig. 2.—Chittenden Valley and Lake, looking southwest.

its lower reaches and northeast-southwest where it turns and merges into the Santa Clara Valley. The slopes of the hills in the Santa Cruz Mountains are unusually steep, occasionally obtaining an incline of forty-five degrees. See pl. 13, fig. 1.

The Pajaro Valley is really composed of three broad alluvial plains. The lowest of these plains reaches down to the Bay of Monterey. To the east of this, and separated from it by a low range of hills, is a circular valley in which is situated the town of Aromas. Over these two plains the river meanders in sweeping curves. Still farther east is the Chittenden Valley. (See pl. 13, fig. 2.) This valley shows signs of recent meandering but recent uplift has forced the river to the south. Southeast of here lies the San Benito Valley, a flat, fertile plain with the San Benito River flowing in sweeping curves but intrenched in its own flood-plain to a depth of 25 or more feet. Through the barriers separating the three lower plains the Pajaro River has cut sharp cañons. The divide between the San Francisco Bay and the Monterey Bay drainage area is a very gradual rise in the floor of the Santa Clara Valley, near the town of Morgan Hill.

SUMMARY STATEMENT OF THE GEOLOGY.

In general the geological features of the area studied comprise a basement complex of altered sediments invaded by a plutonic mass upon which rests the Franciscan series. The latter has been intruded by peridotites now altered to serpentine. The Shasta-Chico rocks are absent and the oldest rocks resting on the Franciscan are of Miocene age. The San Pablo series rests unconformably upon the Miocene and the Merced unconformably upon the San Pablo. Above the Merced is a thick series of fresh-water beds with occasional intercalations of marine strata. The lower Miocene formation is the source of the oil of the district and the oil is reached by borings along an anticline to the north of Chittenden. The most interesting and important feature of the field is the clearly exposed unconformable relation of the San Pablo to the Miocene.

PRE-FRANCISCAN ROCKS.

Sedimentary.—In the area mapped no sedimentaries of age earlier than the Franciscan were noted. About twelve miles south of Chittenden and back of the town of San Juan in San Benito County, however, some rather extensive deposits of limestone were studied. These remnants of a once probably extensive terrane are older than the granitic rocks of the Gavilan range. The contacts are intrusive and the limestone, or marble, is highly crystalline. Much of it is very pure, as the accompanying analyses show.

Analyses of Limestone.[1]

	I	II
Moisture	.10	.10
SiO_2 and insol. res.	2.62	1.00
$CaCO_3$	96.23	96.62
Fe_2O_3	.30	.05
Al_2O_3	.40	trace
MgO	.24	2.19
Organic Matter		.10
	99.89	100.06

Very little time was spent studying these interesting deposits, but it may be mentioned that the opportunities for study are excellent owing to the fresh contacts exposed by prospect tunnels. There is a great deal of limestone in this region ranging from a dark blue variety to an almost pure white highly crystalline marble carrying 96 per cent calcium carbonate. Small particles of graphite are scattered through the marble. Similar deposits of limestone have been noted in the Santa Cruz quadrangle[2] and elsewhere. Not all of this limestone is as pure as the two samples analysed. These analyses are of samples taken from the deposits to be used in the manufacture of Portland cement. There are extensive deposits in this same region which have not been so much affected by the intrusion of the diorite, and are worthy of careful search for fossil remains.

[1] By permission of the San Juan Portland Cement Company.

[2] U. S. Geol. Surv., folio No. 163, 1909.

Igneous.—Extending across the southwest part of the area and forming a part of the same plutonic mass which enters into the composition of the Gavilan range to the south, and probably also the Santa Cruz range to the north, is an extensive mass of rather basic quartz-diorite. This rock, together with the more acidic facies to the north and to the south, forms the base of the Coast Ranges.

The geologic relations of the quartz-diorite, its petrographic and chemical characters, were discussed by Reid[3] in his paper on the igneous rocks near Pajaro. Reid's views have been in the main, corroborated by the writer. Rather extensive quarrying at Logan near the Pajaro River Cañon has exposed the rock-mass so that its relations to the overlying sedimentaries can be well studied. Southeast from this point the diorite is exposed in the transverse valleys for a mile or more, and extensive areas of it are found in the vicinity of Fremont Peak to the south. North of the Pajaro River the diorite quickly disappears beneath the overlying sedimentaries, and does not reappear on the surface again for several miles.

Generally speaking, the plutonic mass may be said to lie in the anticline of a somewhat complicated fold of Miocene sediments. The contact, of course, is depositional and not intrusive. The lowest sedimentary rock exposed as resting on the diorite is a coarse, non-fossiliferous, brown sandstone. This is well exposed near the quarry on the railroad track just south of Logan. Above this, conformably, lie great thicknesses of Miocene shale. Resting across the truncated edges of both sandstone and shale beds and across the eroded surface of the diorite, is a series of friable sands and gravels which are probably closely allied to the Merced formation. The upper surface of the diorite mass is water-worn and these sands, with an abundant marine fauna, fill the crevices. These relations are best seen on the southwestern side of the range or hills formed by the diorite mass. On the northeastern side these relations are obscured by faulting along the San Andreas rift.

The San Andreas fault-zone is quite broad in this vicinity and the fracturing of the diorite has been extensive, so that

[3] Univ. Calif. Publ. Bull. Dept. Geol., 3, 1902, pp. 173-190.

blasting in quarrying is unnecessary. The fractures are so open in places that the overlying sands are washed into them and in the rainy seasons considerable trouble arises from sliding.

The petrographic character and the chemical composition of the various phases of the diorite were fully set forth in Reid's paper, to which the reader is referred.

FRANCISCAN SERIES.

Franciscan rocks, together with the serpentine bodies to be described, occupy much of the northern part of the area mapped. This complicated terrane shows great erosional resistance and hence forms a prominent northwest-southeast ridge extending far beyond the limits of the map to the northwest. In the area mapped, the southern end of this "core" of Franciscan rocks plunges beneath the Tertiary sedimentaries of the Santa Clara Valley.

Detailed mapping within the Franciscan terrane was not attempted and the formation as a whole was roughly divided into two parts: the sandstones and radiolarian cherts, and the foraminiferal limestones. The latter are probably younger in age than the former.

The older division of the formation is composed in the main of a hard, dark gray sandstone. Interbedded seams of black foliated shale are not uncommon, and in one place was noted a rather large mass of a very coarse white sandstone with a scattering of large pebbles. The great mass of sandstone is underlain by a thick accumulation of coarse conglomerate. (See pl. 14, fig. 1.) The radiolarian cherts are abundant throughout the terrane, but in no place do they outcrop favorably for the study of their stratigraphic relations.

The foraminiferal limestone is exceedingly well developed in the region and forms extensive outcrops, in most of which the intercalation of layers of chert is a characteristic feature. It is thought unnecessary to enter into any detailed discussion of the microscopic characteristics and minute structural relations of the rocks composing the Franciscan series. This phase of the

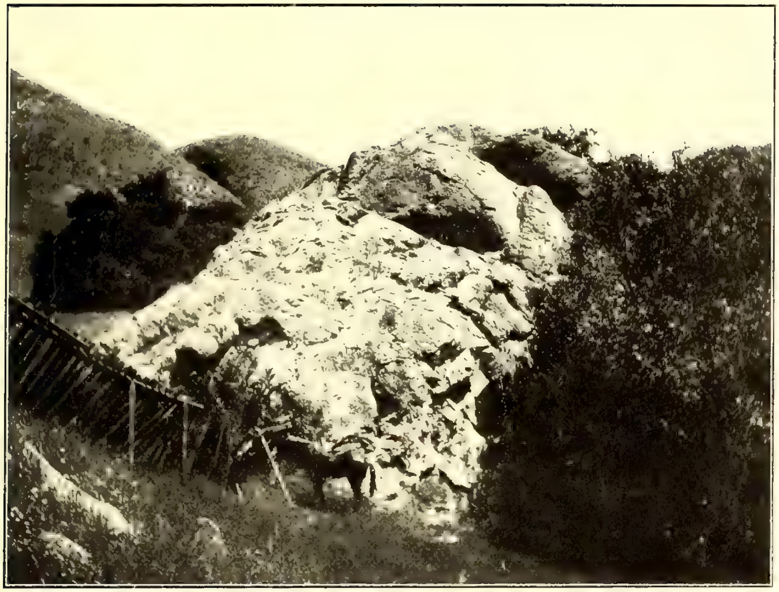

Fig. 1.—Massive outcrop of Franciscan conglomerate.

Fig. 2.—Pescadero Cañon, looking west.

subject has been thoroughly presented by Lawson[4], Ransome[5], and others.

There is more or less uniformity in the strike and dip of the strata over the region in question. A general northwest-southeast strike with a northeast dip of from 30 to 45 degrees prevails. Within small limits, however, there is much variation to the strike and dip, and the whole terrane exhibits evidences of considerable twisting and shearing.

This area of Franciscan rocks was evidently deeply buried beneath the great thickness of Miocene shales but formed a land area during at least the lower part of San Pablo time, and was exposed to erosion then, as the basal divisions of the San Pablo formation carry large amounts of Franciscan rock fragments.

SERPENTINE.

Little need be said in regard to the altered peridotites of this region. The occurrences are all similar to those noted elsewhere in the Coast Ranges where areas of Franciscan rocks have been studied. The original peridotite in its altered condition was not found. Some of the occurrences, however, are of sufficient interest structurally to be worthy of note.

There are four areas of serpentine on the geological map. Two of these, on the north side of La Brea Creek, are evidently connected and form one intrusive body. The most interesting by far of these masses is the irregular one in the extreme northern part of the area mapped. The structure of this body was plainly evident in the field and its contacts with the intruded sedimentaries are all clear and decisive. The lower part of the mass is intruded between the bedding planes of Franciscan sandstone, while the upper part lies across the broken edges of the country rock and in cross-section shows a thin layer of serpentine, the overlying sandstone having been removed by erosion.

The serpentine body just south of here is also intrusive between the bedding planes and may have been at one time structurally connected with the mass above it.

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[4] 15th Ann, Rpt. U. S. G. S.

[5] Univ. Calif. Publ. Bull. Dept. Geol., 1, 1894, pp. 193-233.

The two areas of serpentine on the north side of La Brea Creek are interesting mainly for their peculiar relationship to the overlying sedimentaries. The easterly of these two areas appears on the map to lie between the two basal divisions of the San Pablo formation. There is more or less overlapping of the sedimentaries and it would appear that in lower San Pablo time, while the basal conglomerates of that formation were being deposited, the serpentine protruded above the sediments. During this time depression kept pace with sedimentation and the serpentine was covered by the second division of the San Pablo. These two areas of serpentine, as has been mentioned, are in all probability outcrops of a single mass which was intruded into the Franciscan rocks.

In general, the serpentine bodies appear to have the form of laccolithic sills and prior to the great amount of erosion to which the Franciscan rocks were subjected may have formed one connected series of sills.

MIOCENE SERIES.

Lower Miocene.—The lowest Tertiary formation exposed in the area mapped is probably of lower Miocene age. The formation lies conformably beneath a great thickness of Monterey shale and is separated from it, in the discussion, on lithologic grounds. There are several thick beds of siliceous shale in the terrane which have tentatively been called Lower Miocene, but the presence of large amounts of sandstone, clay shale and conglomerate distinguish it from the overlying Monterey. This series of beds is very similar to the Temblor beds of the Monte Diablo range described by F. M. Anderson[6]. The marked overlapping of the Monterey shales on the Temblor beds as noted by Anderson is also a prominent feature with the Monterey shales on the Lower Miocene of the Pajaro Valley region.

Numerous casts of fossil remains in a poor state of preservation were found in these beds exposed along La Brea Creek; but most of these could not be identified and the few that were recognizable were forms of wide range in the Tertiary.

[6] Proc. Cal. Acad. Sci., 3rd ser., 2, 1905, p. 168, et seq.; and 4th ser., 3, 1908, pp. 18-20.

These Lower Miocene beds are exposed best along the La Brea Creek where they form an acute anticline. This formation holds the oil of the region and the logs of the oil wells, on La Brea Creek, kindly loaned by the Watsonville Oil Company, indicate a thickness of at least 1500 feet. Most of this thickness is of clay shale, sandstone, and siliceous shale. Conglomerates are less frequent. The oil occurs in the sandstone, for the most part, though several of the wells penetrated rich shale members.

Another large but doubtfully mapped area of Lower Miocene beds is exposed on the south slope of the Pescadero cañon, and occupies a faulted anticline. (See pl. 14, fig. 2.)

Monterey Shale.—The predominant formation of the Miocene, and the one which, structurally, has affected to a great extent the present topography of the region, is the great thickness of bituminous shale. A very considerable part of this formation has been removed by erosion, and while its present maximum thickness is about 3000 feet, it was doubtless originally much thicker. Strata of subsequent age in the region have been, in great part, derived from these shales and we are forced to the conclusion that this formation has been much in evidence in the areal geology since its first uplift above sea-level.

The Monterey shale, as a whole, is a remarkably uniform formation and the conditions under which the beds were deposited must have been stationary and uniform through long periods of time. The shales vary in color from an almost pure white to a medium brown and the texture is very fine, varying only within small limits. Where these beds rest upon the Franciscan rocks in the northern part of the area, there is a slight coarseness in texture and some of the strata here may properly be called sandstone. Interspaced at fairly regular intervals throughout the formation, but especially in its lower part, are beds, varying in thickness from one to three feet, holding a high percentage of lime. These beds always form prominent outcrops, and north of La Brea Creek form the only means of determining the structure of the formation as a whole in that part of the area. Just north of Chittenden Lake there are several beds of banded chert, some specimens of which are translucent.

These shales, in the vicinity of Shale Mountain near Chittenden, average 76 per cent. in silica, though many of the beds run much higher than this as the following analysis will show:

Analysis of Monterey Shale from Near Chittenden.

	Per cent.
SiO_2	87.02
Al_2O_3	2.97
CaO	1.12
MgO	.25
Loss on ignition	7.40
	98.76

Only two species of fossils were recognized, *Pecten peckhami* and *Tellina congesta,* the former being exceedingly abundant.

The Monterey shale rests upon the diorite in the southwestern part, and upon the Franciscan rocks in the northern part of the area mapped. In the sedimentary basin between the two contacts, the shale formation has been compressed into four synclines and three anticlines, all with general northwest-southeast axes. At both contacts the shale overlaps the beds mapped as Lower Miocene and hence these latter beds appear only at the surface in the two central eroded anticlines. Again here as with the Franciscan rocks, these structural features are general. Within smaller limits the structure becomes exceedingly complicated. Some of the complications seem, however, to hold good over the entire area. The anticlines are as a rule simple, while the bases of the synclines exhibit close contorted foldings. This is best seen near the Pajaro River at the Southern Pacific Railroad bridge. Here, at the base of the syncline the beds are twisted into a number of overthrust folds which gradually die out to the northeast and to the southwest where the strikes and dips become fairly uniform. This state of affairs is to be expected, however, where a thick, uniform, sedimentary unit is uplifted and folded. The anticlinal portions of the terrane have practically little vertical resistance to overcome while the synclinal portions are resisted by the underlying rocks and therefore have less vertical compensation. The result is, naturally, intense folding in the synclines.

Faulting of the Monterey shale is frequent. The numerous small faults were not mapped. The active San Andreas fault cuts, of course, all the formations of the region through which it passes. The Pescadero anticline is broken down by a fault of considerable magnitude with the downthrow on the north.

SAN PABLO FORMATION.

The San Pablo formation is by far the most interesting terrane in the region studied. The section is accessible and well developed and its stratigraphic relations to both the underlying and overlying formations are exceedingly clear in the field. The writer very much regrets that time and lack of knowledge of Coast Range faunas prevented him from making a closer palaeontological study of this formation as here developed.

The formation is called the San Pablo because it possesses the widespread lithologic characteristics and the structural relations of that formation noted elsewhere.

The typical azure blue sandstones are here prominent and well developed. It is believed that this formation is the equivalent of most, if not all, of the Santa Margarita, Jacalitos, and Etchegoin formations described by R. Anderson[7].

For purposes of discussion and the better to illustrate structure in mapping, the San Pablo formation is here divided upon a lithologic basis into five divisions: A, B, C, D, and E. This division is not expected to stand from a stratigraphic point of view but is simply made for convenience. That the formation is divisible into members on palaeontologic grounds is certain and a more detailed study of the fossil horizons in this region may lead to a convenient and permanent subdivision.

The different members, especially the lower ones, vary in thickness; so that while the maximum thickness of the formation as a whole is about 1200 feet, taking the maximum thickness of each of the five members the total thickness is 3000 feet in this region.

Member A.—This member consists of a series of coarse conglomerates and dark brown, in some cases almost black, sandstones. Exposed surfaces of these beds are light gray in color.

[7] U. S. Geol. Surv., Bull. No. 357, 1908, pp. 35-55.

The thickness of this member varies from 150 feet to 1000 feet. The predominant conglomeratic constituent of this member is fragmentary Monterey shale which shows very little water action. Over small areas, especially in the northern part of the region, Franciscan sandstones and cherts enter largely into the make-up of these conglomerates. While marine fossils are entirely absent from these basal beds, there is an abundant scattering of soft carbonaceous, evidently plant, material. These beds rest unconformably upon the Monterey shale (see pl. 15), and upon the Franciscan rocks in the northern part of the area.

The best section for detailed study is just north of Pescadero Creek, beginning at the actual contact, here plainly visible, between the conglomerates of the San Pablo and the Monterey shales shown in plate 15.

The shale beds here strike N. 48° E. and dip 57° to the northwest. Upon the fairly even erosion surface of the shale rest the San Pablo conglomerates, with a strike almost due east and west and with a northerly dip of 10°. The unconformable relations between the formations are therefore clear and decisive. The detailed section of Member A is as follows:

		feet.
7.	Coarse conglomerates	50
6.	Conglomerates and sandstones	25
5.	Coarse conglomerates	30
4.	Conglomerates and sandstones	20
3.	Coarse conglomerates	40
2.	Hard sandstone	6
1.	Conglomerates and sandstones	20
	Unconformity	
	Monterey Shale	191

Some of the beds of this section are worthy of special description. Numbers 1, 4, and 6 are very friable and soft and do not give rise to prominent outcrops. The sandy and pebbly layers are of irregular thickness. Number 2 is a fairly hard, dark-brown sandstone of even texture. It forms a prominent outcrop standing out as a vertical wall on the ridge where the section was studied. Numbers 3, 5, and 7 are the prominent beds of the section. They are exceedingly coarse in texture, the conglomeratic material being mostly irregular shale fragments of all sizes. These three beds resist erosion exceptionally well

Fig. 1.—Detail of unconformity between Monterey and San Pablo formations.

Fig. 2.—Detail of unconformity between Monterey and San Pablo formations.

and form prominent benches on the hill slopes. In the cañon to the east of the section ridge they form three vertical walls. The sandstone layers are in some cases impregnated with the residues from evaporated petroleum which has seeped up through the underlying shales. Many of these seepages are quite active.

The basal conglomerates (Member A), of the San Pablo formation occupy a considerable area over the region and considerable patches of these beds are of frequent occurrence. The coarse conglomerate layers stand out prominently wherever this member was seen. At the east end of La Brea cañon the conglomerates which here rest on serpentine and which contain large amounts of that rock and fragments of Franciscan rocks with a scattering of shale, are overlapped by the B member of the San Pablo formation. Here the B member loses its characteristic color and appearance owing to the absorption of petroliferous material from active oil seepages.

Members B and C.—These two members of the San Pablo formation are separated more or less arbitrarily to better emphasize structure in mapping. Taken together these beds vary in thickness from 300 to 1000 feet and consist of a gradational series of light azure blue sandstones, quite coarse at the base and gradually grading into a fine-grained hard shale which has an almost conchoidal fracture near the top. This blue color, as is well known, is one of the characteristic lithologic features of the San Pablo formation over wide areas throughout the central Coast Ranges of California. These beds are best exposed on the south slope of La Brea cañon and north of Pescadero Creek in the central part of the area mapped, though they do not form prominent outcrops at any point.

The nature of these sediments may best be seen in the lower or coarser parts of the members. The rock here is more or less friable and is seen to consist of round grains of white sand covered with a film of pasty light blue material.

Member D.—This member consists of a fine to medium grained sandstone varying in thickness from 300 to 600 feet. The thickness of this division of the San Pablo formation is fairly constant over wide areas in contradistinction to the beds below it. The lower beds are believed to be of continental

origin while Member D is undoubtedly marine and so we would expect it to be more uniform in thickness than the lower members.

Parts of the member are much harder than others and form prominent ridges all along the northern and western slopes of La Brea Ridge. One bed, about 30 feet thick, forms one continuous vertical wall from the eastern end of La Brea cañon around the Pescadero Creek. This bed is extremely fossiliferous in parts, in certain places being almost entirely composed of fossil remains. The following species were identified:

Pecten ashleyi	*Tresus nuttalli*
Pecten oweni	*Mulinea densata*
Ostrea, sp?. In great abundance.	*Mya*, sp?
Mytilus, sp?	*Tapes*, sp?
Mytilus, n. sp.	*Standella nasuta*
Cardium, sp.	*Macoma nasuta*
Cardium blandum	*Crepidula princeps*
Arca trilineata	*Prupura*, sp?
Macoma nasuta	*Drillia, sp?*
Pectunculus septentrionalis	*Balanus*, sp?
Panopea generosa	

Member E.—This member is about 400 feet thick and consists of coarse sandstone usually brown, but on close inspection is seen to have a slight bluish tinge. This bed becomes exceedingly coarse and conglomeratic at the top. Prominent outcrops show cavernous weatherings to a marked degree. This feature is believed to be characteristic of the uppermost San Pablo beds elsewhere. This upper division of the San Pablo formation is not as fossiliferous as member D nor do the fossils extend to the top of the series. Certain fine-grained layers of this member are exceedingly gritty to the touch, and it is probable that volcanic ash enters into their composition.

General Features of the San Pablo Formation.—The San Pablo formation as mapped in this region occupies a broad synclinal basin over the central part of the area. The floor of this basin is for the most part Monterey shale but this floor has been deformed in the post-San Pablo uplift. The outlying areas of the basal conglomerates were evidently laid down in the same sedimentary basin, but the whole basin has suffered differential movement and so the dips and strikes of the beds

vary. The formation undoubtedly covered a much larger area than it now does, and what is left, though complete in section, is but a remnant of a once very extensive formation.

The complete section of the San Pablo formation in this region is then as follows:

	Feet.
E. Coarse conglomeratic sandstones, fossiliferous at the base, and holding much volcanic material	400
D. Fine to medium grained brown sandstone, with several hard layers, extremely fossiliferous	300 to 600
B. and C. Azure blue sandstone coarse at the base and very fine near the top	300 to 1000
A. Coarse conglomerates and dark colored sandstones	150 to 1000
	1150 to 2600

THE SANTA MARGARITA FORMATION.

About one mile west of the edge of the area mapped, and just north of the Pajaro River, is a formation composed of white sandstone which is quite friable and which breaks down into a pure white quartzose sand. Fossils are plentiful in these beds but no complete collection was made. There are many beds practically composed of specimens of *Astrodapsis antiselli*, the characteristic echinoid of the Santa Margarita formation. These beds have quite a wide areal distribution through Santa Cruz county and in the Salinas Valley on the south[8]. The unconformable relations between these beds and the Monterey shale are well defined but nowhere have the actual relations in the field between the Santa Margarita and the San Pablo been noted. It seems impossible that two such dissimilar formations could have been contemporaneously deposited so close together as is the case in the Pajaro Valley region without some interdigitation. It would appear from the text of the Santa Cruz folio that the beds there mapped as Santa Margarita are the downward conformable continuation of the Purisima which passes up equally conformably into the Merced. It is thus highly probable that the white sandstones here referred to, and which in the folio are called Santa Marguarita, are later than San Pablo of the

[8] U. S. Geol. Surv., folio No. 163, 1909.

Chittenden section. The stratigraphic relations of the Santa Margarita formation will doubtless in time be more satisfactorily determined and the brief mention of the occurrences in this region may point out a favorable field for investigation.

MERCED AND PURISIMA FORMATIONS.

In the Pajaro Valley region a thick series of marine beds lies unconformably over the San Pablo formation. The actual contacts between these two formations are obscure and doubtful. That these beds, here called Merced and Purisima, overlie the San Pablo is evident and discordance of strike and dip point toward a marked unconformity. These beds overlie unconformably the Monterey shales over large areas and this fact points towards a large erosion interval between San Pablo and Merced time.

The Purisima and Merced formations are not here separated. They form a conformable series wherever noted in this part of the State, and their separation is not a simple problem, especially in the Pajaro Valley region, where the areas of these rocks are devoid of outcrop and where railroad cuts form almost the only means of detailed study in the field. By means of squirrel burrows and soil it is not usually difficult to outline the areas of these rocks.

The formation is about 1500 feet thick and it is therefore probable that only a part of the total Merced is present. The Pajaro Valley is practically sculptured in Merced rocks. These beds form a belt passing from the lower Pajaro and Salinas valleys across the diorite and along the upper Pajaro Valley to where the river of that name turns northeast. The surface of the diorite just south of the Pajaro River has been exposed by hydraulicking and here the Merced beds, composed of very fossiliferous friable sands and gravels, are well exposed. In the railroad cut just east of Chittenden there is another good exposure. That the Merced beds pass over the diorite and into the upper Pajaro Valley is certain. The uppermost surface of the diorite is well water-worn, and the crevices of the rocks are filled with sand and fossil remains; and foreign water-worn material is scattered over the ground on the highest points of

the range of hills formed by the resistant plutonic rock. The fossils throughout the formation are not generally scattered but are localized in beds from a few inches up to several feet in thickness. These beds are very hard and have prevented excessive erosion of the formation as a whole.

The recent Santa Cruz folio by Branner, R. Arnold, and Newsome notes Purisima beds along the east flank of the Santa Cruz range and limits the Merced to the sea-coast. It is evident that during Merced time a deep bay or strait existed over the Pajaro Valley region and that Merced sediments were deposited in this trough as far inland as the Santa Clara Valley.

The following fossils were identified from the formation here called Merced:

Arca trilineata
Arca microdonta
Standella californica
Standella falcata
Tresus nuttalli
Macoma nasuta
Callista subdiaphana
Solen sicarius
Mytilus, sp (?)
Mytilus edulis
Ostrea, sp (?)
Purpura canaliculata
Purpura, sp (?)
Crepidula princeps
Neverita recluziana
Olivella boetica
Amycla gausapata
Amycla undata
Nassa perpinguis
Echinarachnius excentricus
Balanus, sp (?)

FRESH-WATER FORMATION.

Exposed all along the Southern Pacific Railroad track for a mile south of Sargent is a thick formation of clays, sandstones, and gravels which are undoubtedly, in the main, of fresh-water origin. These beds flank the eastern slope of the Santa Cruz range and in general dip towards the Santa Clara Valley, though in places they are quite highly tilted and their structure is slightly complicated. The total thickness of the formation is at least 800 feet. Near the junction of the San Benito and the Pajaro valleys the discordance in dip and strike between the beds which have been called Merced and these fresh-water beds points towards at least a local unconformity between the two, but this is not certain. The fresh-water formation rests on San Pablo, Monterey, and Franciscan rocks farther north. The formation yields no outcrops except in intrenched creek beds

along railroad and road cuts. The contact between these beds and the Merced is, therefore, not clear and the structural relations remain indeterminate.

It is probable that this formation is the same as the Santa Clara formation described by Branner[9] farther north on the east flank of the Santa Cruz range; but it resembles both in its general characteristics and in its approximate position in the geological scale the earlier described Orindan of Lawson[10] and may perhaps be the correlative of the latter. The entire contemporaneity of the fresh-water beds of the Pajaro Valley region and the Merced formation is doubted. While it is probable that in part they are contemporaneous, it seems impossible that the two should be so well developed in such close proximity as is here noted and yet be entirely of the same period. The writer believes that the lower part of the fresh-water formation is contemporaneous with the upper part of the Merced but that the former lies, at least in the Pajaro Valley, above the lower Merced.

In the section of the fresh-water formation exposed for a mile south of Sargent along the railroad track, the beds dip (see pl. 16, fig. 1) 21° to the south. In this whole section in its lower part there are two thin beds containing marine fossils, indicating brief invasions of the sea over the region of delta accumulation.

PLEISTOCENE AND RECENT FORMATIONS.

There is a marked unconformity between the fresh-water formation and the recent alluvial deposits. No gradation, as has been noted farther north between the Santa Clara beds and the alluvium of the Santa Clara Valley, exists in the Pajaro Valley region. Very recent changes, which have entrenched the streams below the base of the alluvial deposits, have exposed the actual contact between the disturbed fresh-water formation and the more recent beds; and the unconformable relations are striking.

All the larger streams have been entrenched in their own alluvial deposits, thus exposing sections. The river gravels along La Brea and Pescadero creeks contain stumps of *Sequoia.*

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[9] U. S. G. S., Folio 163.

[10] Univ. Calif. Publ. Bull. Dept. Geol., 2, 1902, pp. 371-374.

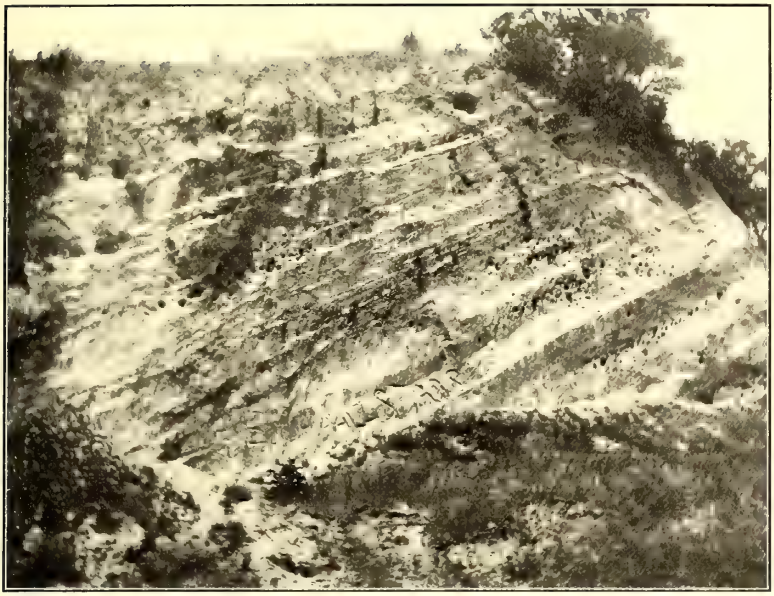


Fig. 1.—Tilted fresh-water beds south of Sargent, looking west.

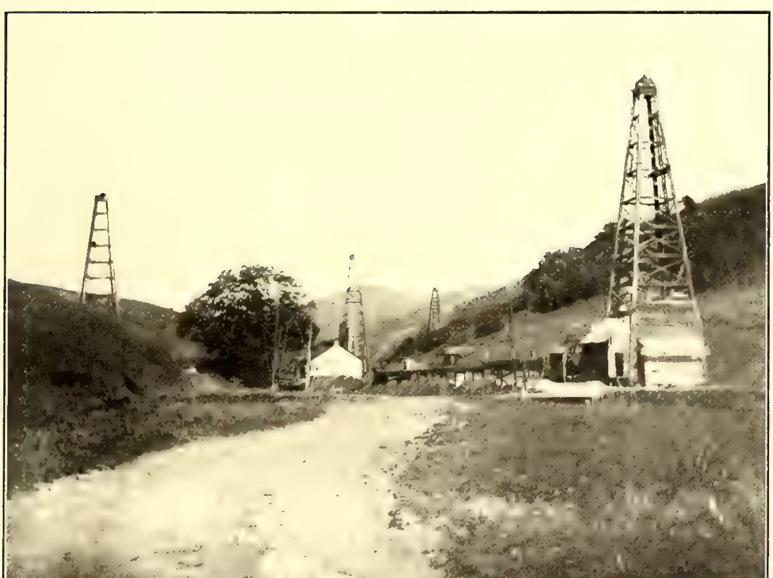


Fig. 2.—Oil wells on La Brea Creek.

GEOLOGIC HISTORY.

Pre-Franciscan.—Little is known of the Pre-Franciscan geologic history of the central Coast Ranges and no additional data was procured from the study of the Pajaro Valley region. The intrusion of the quartz-diorite into a much older series of sedimentaries whose age is not known, uplift, and the erosion of all but remnants of the sedimentaries, are all the records we have of that long period of time.

Franciscan Time.—Little also can we learn from a study of the Franciscan rocks of the conditions of deposition and the physical geography of Franciscan time. That the period of deposition was a long one and that conditions changed materially during that time we know.

Post-Franciscan and Pre-Tertiary.—The chief record in the Pajaro Valley region of the time between the uplift of the Franciscan rocks and the Tertiary period is that of a long period of erosion of the Franciscan. Some time during that interval these rocks were invaded by peridotitic magma, which formed laccolithic bodies. The Shasta-Chico is not represented in the section.

Tertiary. Pre-Miocene.—Up to the beginning of the Miocene there is no sedimentary record in this region.

Miocene.—The lowest Tertiary rocks exposed are considered to be of Lower Miocene age. Their lithologic characters indicate a period of oscillation. Sandstones, conglomerates, and shales follow one another without any definite sequence and so we may consider that the depth of water over the area varied considerably during this time. The Franciscan rocks evidently formed land bodies at this time, as we find the Monterey shales overlapping the Lower Miocene and resting directly upon the Franciscan.

At the beginning of Monterey time, without interruption of deposition, there was a widespread submergence and deep water prevailed all through the Monterey time, the depositional conditions remaining constant and uniform. The Franciscan rocks were doubtless largely covered by a thick mantle of sediments. Subsequent to Monterey time and before the San Pablo there was a profound uplift, accompanied by folding and faulting and there was inaugurated a long period of erosion.

San Pablo Time.—The San Pablo rocks indicate in general slow submergence followed by a slow uplift during which deposition went on continuously.

The basal conglomerates of the San Pablo formation indicate non-marine sedimentation over a basin whose floor consisted of the eroded Monterey and Franciscan rocks. The erosion period of the pre-San Pablo rocks had not ceased and both Franciscan and Monterey rocks were prominent features of the land mass, supplying waste to form the conglomerates of the San Pablo.

Submergence continued and the blue sandstones, growing finer and finer towards the top, were deposited, overlapping the basal conglomerates. Distant volcanoes contributed their fine ashes.

At just what time marine conditions were inaugurated is doubtful, but they continued to the end of San Pablo time. Uplift began and the brown fossiliferous sandstones were deposited, followed by the conglomeratic sandstones at the top of the San Pablo formation. This uplift continued and the San Pablo sediments emerged from the sea. The uplift was not accompanied, apparently, by any profound disturbance. An erosion interval of perhaps not great length ensued and the land was again slowly submerged to receive the Merced sediments.

Merced and Later.—During Merced time the diorite of the Santa Cruz range became submerged and its surface was exposed to wave action. The sea transgressed over part of the land and evidently formed a deep bay across the region now occupied by the Pajaro Valley. In this bay marine sedimentation went on. During this period sedimentation was temporarily interrupted and fresh-water conditions prevailed in the Santa Clara Valley and delta beds were deposited. At least twice during the earlier part of this delta accumulation the sea overflowed the fresh-water depositional area and a sparse marine life existed for a time, only to be forced out again by the gradual exclusion of the sea and the resumption of fresh-water conditions over this inland basin.

The uplift following the close of the delta deposition was accompanied by considerable tilting and folding. The fresh-water and Merced beds were both affected. In the erosion which

ensued the greater part of the Merced sediments over the Pajaro Valley were removed. The diorite offered more resistance to erosion.

Prior to a very recent uplift the Pajaro River meandered in sweeping curves over the Chittenden Valley and the old river gravels and sands can be followed among the low hills of that basin. Chittenden Lake, which previous to the earthquake of April, 1906, usually dried up during the dry season, occupies a slight depression in this old river course.

This recent slight uplift was the last event in the history of the region. The Pajaro River abandoned its meandering course and intrenched itself close to the steep south slope of the valley. This uplift may have been due to an upward movement on the northeast side of the San Andreas rift, for southwest of the fault in the lower reaches of the Pajaro Valley the river is not intrenched but meanders over the plain in broad curves. At the same time the tributary streams of the Pajaro River all intrench themselves to a depth of about twenty-five feet in their own gravel and alluvial deposits. The San Benito River to the south maintains its meandering course but flows in a trench twenty-five feet below the level valley floor.

ECONOMIC FEATURES.

The economic resources of the region are, in the order of their importance, oil, cement materials, stone, and sand.

Oil.—Indications of oil in profitable quantities are good. The oil-bearing rocks, the Lower Miocene, cover a wide area and the general series of anticlines and synclines which these rocks and the overlying Monterey shales occupy are good indications from a structural point of view. Oil seepages are numerous and occur over wide areas and wherever seen may be taken as an indication of Lower Miocene rocks lying below the surface whatever the suface rock at that particular point may be.

At present there are only two companies in the field, but the output has not, up to the present, been large enough to place the district among the productive oil regions of the state. The Watsonville Oil Company has drilled a number of wells on the La Brea anticline (see pl. 16, fig. 2) and the Sargent's Ranch Oil Company is prospecting at the eastern end of La Brea Cañon.

Besides these there are a number of abandoned wells near Chittenden just south of Shale Mountain.

The La Brea anticline is very acute and is asymetric in form. Hence the wells do not penetrate a great thickness of strata and the logs are misleading in this respect. The upper oil sands are all exposed on the surface by erosion and hence much of the oil has escaped. There are doubtless several oil-bearing sands below and the structure of the rocks is favorable for the location of high-pressure wells. Deep drilling seems to be the only solution of the problem. A thorough and accurate study of the structure of the Lower Miocene rocks should materially aid in locating wells, but no great production can be expected unless the wells are drilled to depths of over 2000 feet.

At the lower end of La Brea Cañon, where the Sargent's Ranch Oil Company is prospecting, the Lower Miocene oil-bearing rocks do not appear on the surface and it is impossible to determine the structure. The close proximity of Franciscan rocks at this point, however, does not point to an anticlinal structure but rather to a synclinal and it would seem that indications are not favorable for large production. By working south, however, and penetrating the fresh-water beds and San Pablo rocks, productive fields may be encountered.

The more reliable of the logs of the Watsonville Oil Company's wells on La Brea Creek are herewith published. It must be remembered that the thickness of the beds indicated are exaggerated owing to oblique penetration.

Well No. 1. Record by C. A. Mitchell.

Material	Thickness feet	Depth feet
(Record missing)	591	591
Blue shale	79	670
Oil sand	34	704
Brown shale (oil and gas)	566	1270
Sand	6	1276
Blue clay	64	1340
Brown shale	26	1366
Blue shale	8	1474
Brown shale	86	1560
Oil sand (dry)	7	1567
Blue clay	5	1572
Brown shale (oil and gas)	31	1603
Brown sandy shale (very rich)	12	1615
Sand (salt water)	5+	1620

Well No. 2. Record by C. A. Mitchell.

Material	Thickness feet	Depth feet
Alluvium	35	35
Blue sandstone	30	65
Conglomerate (water)	5	70
Blue clay	20	90
Yellow clay and conglomerate	25	115
Blue clay	35	150
Blue shale	174	324
Oil sand (tar)	41	365
Blue shale	272	637
Oil sand (oil)	53	690
Brown shale	494	1184
Oil sand (oil)	20	1204
Brown shale	14+	1218

Well No. 4. Record by C. A. Mitchell.

Material	Thickness feet	Depth feet
Alluvium	60	60
Blue shale	160	220
Blue sandstone	26	246
Blue shale	19	265
White shale	5	270
Blue shale	526	796
Blue sandstone	8	804
Oil sand (dry)	12	816
Sandy shale (some oil)	46	862
Brown shale (oil and gas)	280	1142
Hard brown shale	65	1207
Blue shale	5	1212
Brown shale	38	1250
Black clay	15	1265
Brown shale	53	1318
Oil sand	4	1322
Brown shale	32	1352
Oil sand	3	1355
Brown shale	512	1867
Sandy shale	37+	1904

Cement Materials.—The cement materials consist of limestone, shale, and clay. There is no plant producing at present. The San Juan Portland Cement Company is building a 2000-barrel plant at the town of San Juan.

Limestones.—The limestone deposits were mentioned on page 58 and two analyses were given.

Shale.—The available amounts of shale are, of course, practically unlimited. But most of the Monterey shale is probably

too silicious and too low in alumina to be available for cement manufacture.

Clay.—The clay deposits are alluvial and occupy depressions in the old river channel near Chittenden. The deposits cover about thirty-five acres and have a maximum depth of forty feet. This clay is of uniform texture and is dark blue in color. The following analyses of samples from five different borings are available for publication:

Analyses of Clays.

	A	B	C	D	E
SiO_2	59.80	51.62	51.88	52.79	63.26
CaO	2.96	2.67	2.67	3.31	3.05
MgO	2.92	4.24	4.29	4.27	1.40
Fe_2O_3	7.73	7.87	8.20	7.58	6.17
Al_2O_3	15.64	16.83	18.05	18.12	17.26
SO_3	.60	2.03	2.33	1.01	trace
Loss	7.71	10.38	11.87	10.58	7.17
Alkalies	2.64	4.36	.54	2.34	1.69
	100.00	100.00	100.00	100.00	100.00

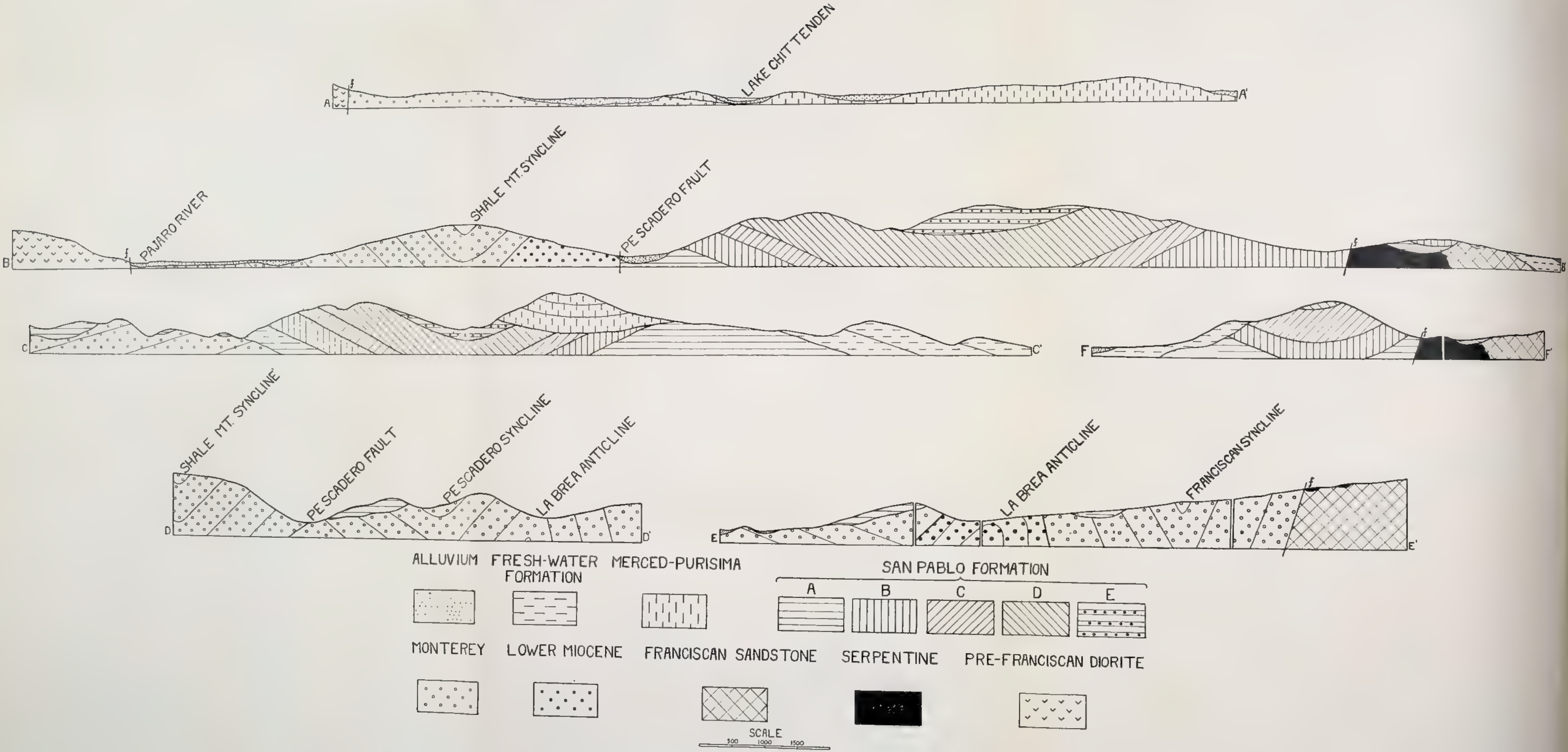
Average samples of the raw materials after being ground, mixed into slurry and clinkered, and the clinker ground to 100 mesh, gave a cement of good color with a specific gravity of 3.28, and the following composition which, it will be seen, falls between the limits of the Chatelier and S. B. Newberry standards.

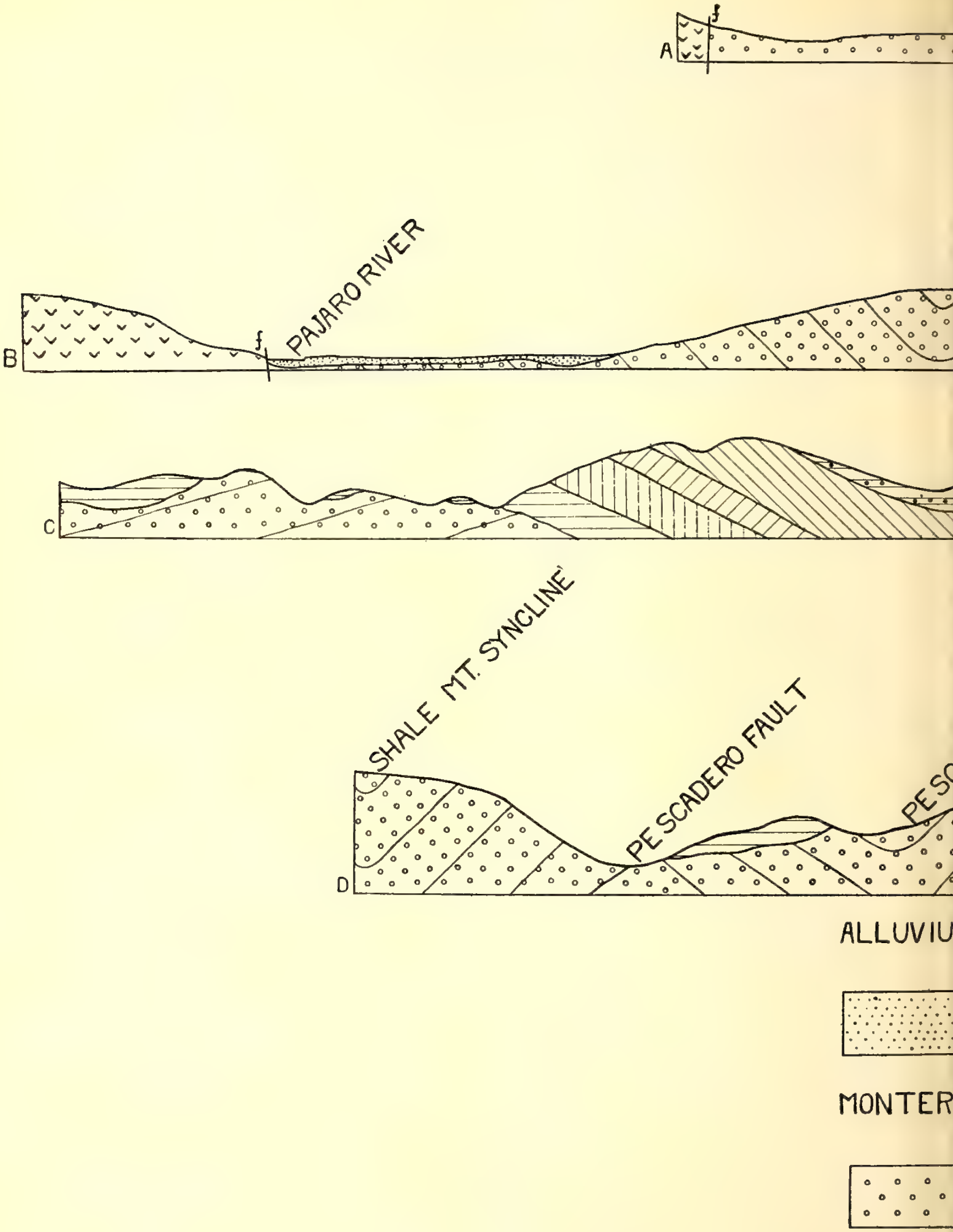
Analysis of Cement.

SiO_2	21.12
Al_2O_3	6.11
Fe_2O_3	3.37
CaO	61.04
MgO	1.11
SO_3	1.01

Stone.—The diorite is quarried extensively at Logan, just south of the Pajaro River and on the Southern Pacific Railroad. The quarry is owned and operated by the Granite Rock Company of Watsonville, California. The rock is so fractured and shattered that blasting is unnecessary, and this renders the stone useless for decorative building purposes. It is used extensively, however, for road-beds and concrete work.

Sand.—The same company use a large quantity of Merced sand for concrete work.


A
LAKE CHITTENDEN
A'
B
PAJARO RIVER
SHALE MT. SYNCLINE
PE SCADERO FAULT
B'
C
C'
F
F'
SHALE MT. SYNCLINE
PE SCADERO FAULT
PE SCADERO SYNCLINE
LA BREA ANTICLINE
D
D'
E
LA BREA ANTICLINE
FRANCISCAN SYNCLINE
E'
ALLUVIUM
FRESH-WATER FORMATION
MERCED-PURISIMA
SAN PABLO FORMATION
A
B
C
D
E
MONTEREY
LOWER MIOCENE
FRANCISCAN SANDSTONE
SERPENTINE
PRE-FRANCISCAN DIORITE
SCALE
500
1000
1500


A
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SHALE MT. SYNCLINE
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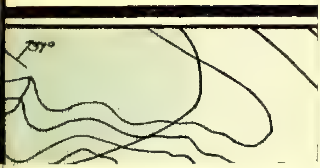

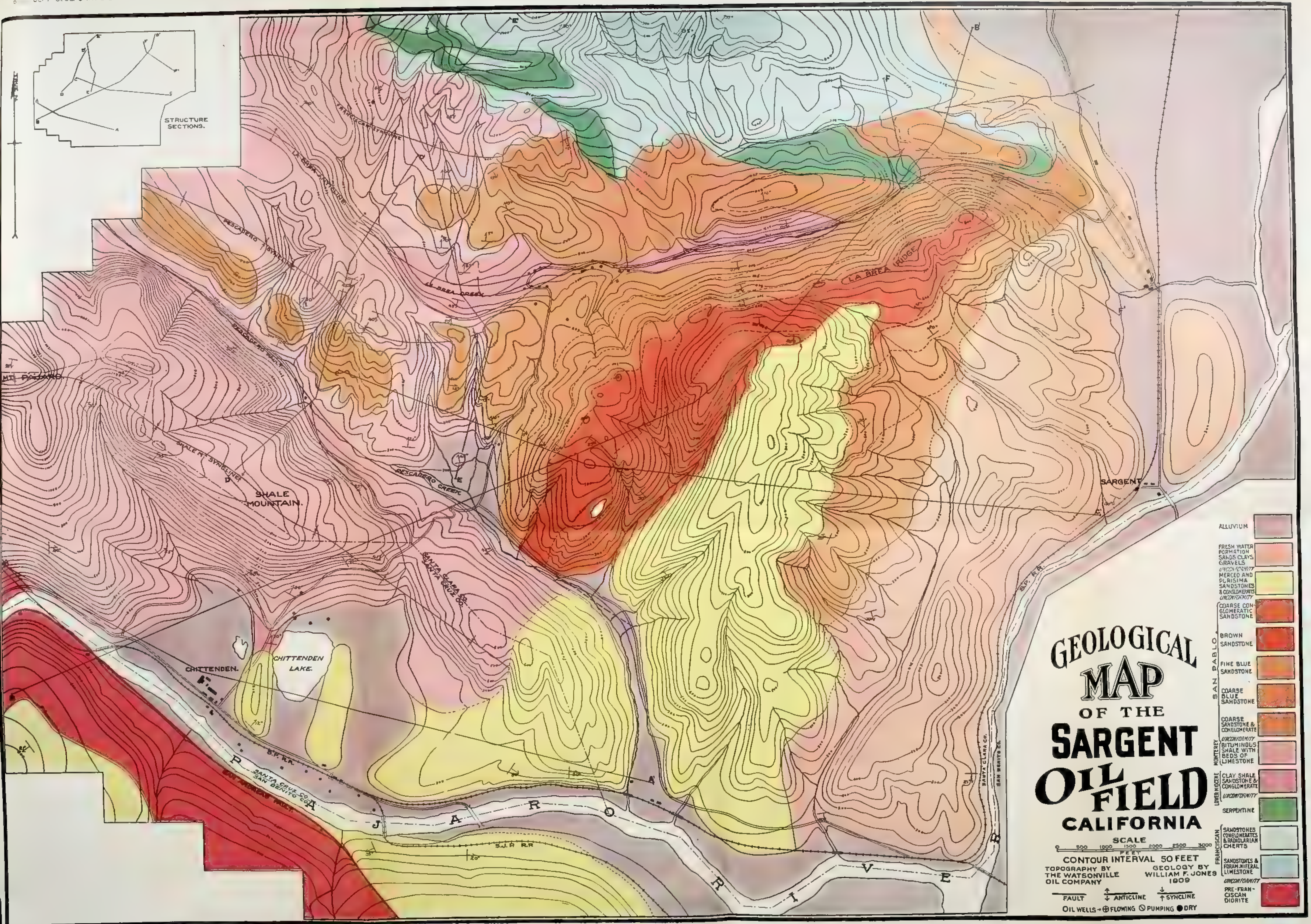
STRUCTURE SECTIONS.
LA BREA ANTICLINE
PESCADERO SYNCLINE
LA BREA CREEK
PESCADERO FAULT
LA BREA RIDGE
MT. PAJARO
SHALE MT. SYNCLINE
SHALE MOUNTAIN.
PESCADERO CREEK
SANTA CLARA CO.
SANTA CRUZ CO.
SARGENT
CHITTENDEN.
CHITTENDEN LAKE.
S.P. R.R.
SANTA CRUZ CO.
SAN BENITO CO.
SAN ANDREAS FAULT
P A J A R O R I V E R
S.J. R. R.
SANTA CLARA CO.
SAN BENITO CO.
ALLUVIUM
FRESH WATER FORMATION SANDS CLAYS GRAVELS
UNCONFORMITY
MERCED AND PURISIMA SANDSTONES & CONGLOMERATES
UNCONFORMITY
SAN PABLO
COARSE CONGLOMERATIC SANDSTONE
BROWN SANDSTONE
FINE BLUE SANDSTONE
COARSE BLUE SANDSTONE
COARSE SANDSTONE & CONGLOMERATE
UNCONFORMITY
MONTEREY
BITUMINOUS SHALE WITH BEDS OF LIMESTONE
LOWER MIOCENE
CLAY SHALE SANDSTONE & CONGLOMERATE
UNCONFORMITY
SERPENTINE
FRANCISCAN
SANDSTONES CONGLOMERATES & RADIOLARIAN CHERTS
SANDSTONES & FORAMINIFERAL LIMESTONE
UNCONFORMITY
PRE-FRANCISCAN DIORITE
GEOLOGICAL MAP OF THE SARGENT OIL FIELD CALIFORNIA
SCALE
0 500 1000 1500 2000 2500 3000
FEET
CONTOUR INTERVAL 50 FEET
TOPOGRAPHY BY THE WATSONVILLE OIL COMPANY
GEOLOGY BY WILLIAM F. JONES 1909
FAULT
ANTICLINE
SYNCLINE
OIL WELLS → FLOWING PUMPING DRY

UNIVERSITY OF CALIFORNIA PUBLICATIONS

BULLETIN OF THE DEPARTMENT OF

GEOLOGY

Vol. 6, No. 4, pp. 79-87 Issued February 4, 1911

ADDITIONS TO THE AVIFAUNA OF THE PLEISTOCENE DEPOSITS AT FOSSIL LAKE, OREGON

BY

LOYE HOLMES MILLER

BERKELEY
THE UNIVERSITY PRESS

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LOYE HOLMES MILLER.

CONTENTS.

INTRODUCTION.

The horizon designated as the Equus Beds in the Fossil Lake[1] region of Oregon has been known to palaeontologists for many years, and the field has been extensively worked by Marsh, Cope, Condon, Sternberg and the University of California. The material representing the bird group has been so critically examined by both Cope and Schuffeldt, that it would seem as though our knowledge of the Pleistocene avifauna of that region bore little chance of improvement. It is the object of the present paper to record certain additions to the known list of species that have recently come to light.

[1] Generally known in the literature as "Silver Lake". Fossil Lake is a small body of water about twenty miles north-east of Silver Lake.

SOURCE AND NATURE OF THE MATERIAL.

During the summer of 1901 an expedition organized and financed by Miss Annie M. Alexander visited the Fossil Lake region for the purpose of collecting vertebrate fossils from the Pleistocene beds. The collections resulting from this expedition were generously donated to the University of California and form part of its collections in vertebrate palaeontology.

The material assembled consists largely of mammalian remains. There are, however some representatives of the fishes,[2] and a very interesting collection of bird material. The avian remains were first placed by Professor John C. Merriam in the hands of Mr. F. A. Lucas for determination and description. Unfortunately that able student of avian osteology was prevented by the pressure of other duties from giving the collection more than a cursory examination, and after retaining the material for some time he returned it to the University with a purely tentative identification of the various species represented. After the lapse of a number of years, the task is assumed by the present writer, who wishes to acknowledge his indebtedness to Mr. Lucas for the suggestions conveyed by the determinations made by him several years earlier.

With the exception of several coracoids and two scapulae, all the determinable material consists of limb bones, with a surprising paucity of the dense tarso-metatarsi. Various possible explanations for this scarcity of tarsi suggest themselves. The most plausible is here offered. On lakes or other large bodies of water the remains of aquatic birds tend to concentrate along the shore-lines. Owing to the buoyant effect of the air stratum retained within the feather coat, the body may float for a prolonged period or until cast upon shore by the prevailing wind. The naked shank is submerged during this time, as a rule, and is subject to more rapid maceration and to the attacks of water fleas or the aquatic larvae of insects. These influences tend to accelerate disarticulation by loss of the binding ligaments. The metapodials would therefore be sown broadcast over a wide area; a result

[2] See Jordan, David S., Fossil Fishes of California. Univ. Calif. Publ. Bull. Dept. Geol., 5, pp. 95-144. 1907.

quite at variance with the concentration of other remains upon the lee shore. Instances in support of this view are abundant in the experiences of the author while collecting the skeletons of sea birds cast upon the beach. The ligaments of the foot and shank are among the first to loosen, making these the parts most frequently wanting in the beach specimens. It is otherwise difficult to account for the preservation of such fragile bones as the pneumatic coracoid, while the dense, strong tarsus is so sparsely represented in the assembled material.

The specimens composing the collection are in a beautiful state of preservation. Where not actually fractured, the form and markings are almost as perfect as though freshly macerated from the Recent specimen. This shows particularly well in such a specimen as the femur of a grebe, where the rugosities are normally so well defined. The cavities of the long bones and the spaces of the cancellated bone where broken are commonly filled with fine yellowish gray sand, which formed the matrix in which they were buried.

PREVIOUS KNOWLEDGE OF THE FOSSIL AVIFAUNA.

The fossil avifauna previously known from the Fossil Lake Beds has been discussed very thoroughly in an extensive memoir by Schuffeldt[3] embodying the results of his examination of the private collections of Cope and Condon. These collections were more extensive than the one at present under discussion. As might be inferred, therefore, the number of species determinable in the California collection is less than that determined by Schuffeldt. There are represented, however, three forms not reported by Schuffeldt, one of which, a species of *Æchmophorus,* is new to science.

The age of the Fossil Lake Beds was assumed by Schuffeldt to be Pliocene. This was the estimate made by Cope from a study of the mammalian fauna, which he correlated with the Subapennine of Europe. The more extended study of various western horizons made by other writers has unquestionably proven the Pleistocene age of these beds.

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[3] Schuffeldt, R. W., Journ. Acad. Nat. Sci. Phil., no. 9, p. 389. 1892.

LIST OF SPECIES KNOWN FROM FOSSIL LAKE.

Schuffeldt enumerates forty-nine species in his discussion of the avifauna as determinable from the two collections examined by him. A list of these species is as follows:

SPECIES RECORDED BY SCHUFFELDT.

Pygopodes	*Æchmophorus occidentalis* (Linnaeus).
	Colymbus holboeli (Reinhardt).
	Colymbus auritus Linnaeus.
	Colymbus nigricollis californicus (Brehm).
	Podilymbus podiceps (Linnaeus).
Longipennes	*Larus argentatus* Pontoppidan.
	Larus robustus Schuffeldt.
	Larus californicus Lawrence.
	Larus oregonus Schuffeldt.
	Larus philadelphia Ord.
	Xema sabini (J. Sabine).
	Sterna elegans Gambell.
	Sterna forsteri Nuttall.
	Hydrocheledon nigra surinamensis (Gmelin).
Steganopodes	*Phalacrocorax macropus* Cope.
	Pelecanus erythrorhynchos Gmelin.
Anseres	*Lophodytes cuculatus* (Linnaeus).
	Anas platyrhynchos (Linnaeus).
	Mareca americana (Gmelin).
	Nettion carolinense (Gmelin).
	Querquedula discors (Linnaeus).
	Querquedula cyanoptera (Vieillot).
	Spatula clypeata (Linnaeus).
	Dafila acuta (Linnaeus).
	Aix sponsa (Linnaeus).
	Marila valisneria (Wilson).
	Glangula islandica (Gmelin).
	Harelda hyemalis (Linnaeus).
	Anser condoni Schuffeldt.
	Anser albifrons gambelli Hartlaub.
	Branta hypsibatus Cope.
	Branta canadensis (Linnaeus).
	Branta propinqua Schuffeldt.
	Chen hyperboreus (Pallas).
	Olor paloregonus Cope.
Odontoglossae	*Phoenicopterus copei* Schuffeldt.
Herodiones	*Ardea paloccidentalis* Schuffeldt.
Palaudicolae	*Fullica americana* Gmelin.
	Fullica minor Schuffeldt.
Limicolae	*Lobipes lobatus* (Linnaeus).

Gallinae	*Tympanuchus palidicinctus* (Ridgeway).
	Pediœcetes phasianellus columbianus (Ord).
	Pediœcetes nanus Schuffeldt.
	Palaeotetrix gilli Schuffeldt.
Accipitres	*Aquila pliogryps* Schuffeldt.
	Aquila sodalis Schuffeldt.
Striges	*Bubo virginianus* (Gmelin).
Passeres	*Euphagus affinis* Schuffeldt.
	Corvus annectens Schuffeldt.

ADDITIONAL SPECIES IN THE CALIFORNIA COLLECTIONS.

Pygopodes	*Æchmophorus lucasi,* n. sp.
Anseres	*Erismatura jamacensis* (Gmelin).
Accipitres	*Circus hudsonius* (Linnaeus).

DESCRIPTION OF SPECIES.

ÆCHMOPHORUS LUCASI, n. sp.

Type specimen[4] no. 12605, Univ. Calif. Col. Vert. Palae., and cotypes nos. 12603 and 12604.

Femur larger than in *Æ. occidentalis* and less curved in the anteroposterior plane. Tarsus stouter in the shaft, with narrower extremities, and with narrower intercotylar tuberosity.

In examining a group of six grebe femora in the collection there readily appeared a division of the group into two series. One, embracing two specimens, corresponded in every particular with the existing species; the other, consisting of four specimens, showed constant characters which were distinctly different from the Recent form. The difference in size is evident upon examination of the table of measurements recorded below. The osteological characters are not at variance except as relates to the degree of curvature of the shaft. The character is not such a one as is readily measured but is easily evident on placing together bones from the two species.

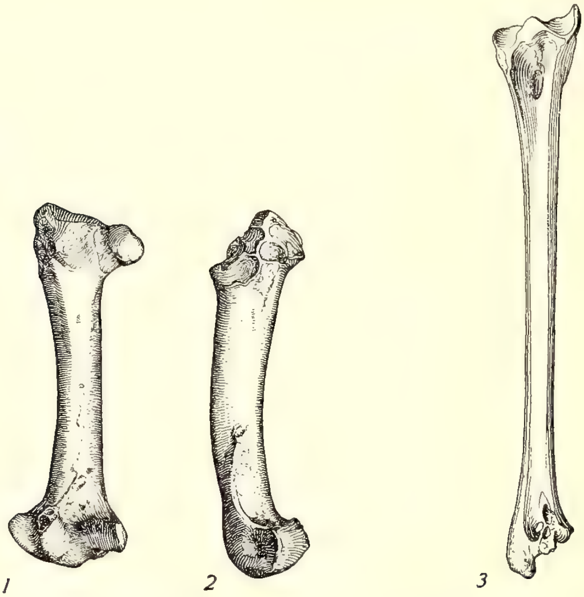
The tarsus of the new form is represented by four specimens. One is perfect except for the loss of the middle trochlea; the others consist of two proximal and one distal fragment. The deviation from the existing species is here noticeable in the proximal end of the bone. The tarsus of *Æ. lucasi* is actually longer and the shaft stouter, but the head is quite appreciably narrower. This compression of the head region has the effect of reducing also, the width of the intercotylar tuberosity—a character at

[4] I take pleasure in naming this species in honor of Mr. F. A. Lucas, in whose hands this collection was originally placed for examination.

once noticeable on comparing the tarsi from the anterior aspect. There is noticeable also an elevation of the inner border of the inner tibial facet to a degree exceeding that seen in the existing species.

The anterior border of the shaft in *Æ. occidentalis* is almost perfectly straight, whereas the same profile in *Æ. lucasi* is decidedly convex.

The coracoid assigned to this species is distinguishable from that of the existing form by its greater length and its very slender shaft. In total length along the inner border, the cotype exceeds the Recent species by three and seven-tenths (3.7) millimeters. The actual transverse diameter of the shaft is, however, three-tenths (0.3) millimeters less at its narrowest point.



1 2 3

Figs. 1 and 2.—*Æchmophorus lucasi.* Femur, natural size. Fig. 1, posterior view; fig. 2, lateral view.

Fig. 3.—*Æchmophorus lucasi.* Tarsometatarsus, anterior view, natural size.

The several differences between the extinct form and the living one seem to point toward the former as a bird of slightly larger body size, as indicated by the longer coracoid; but possibly of weaker powers of flight, as is suggested by the slenderness of that bone. The swimming powers may have been greater, since the posterior limb shows greater robustness of its proximal segment, the femur, and greater length of its distal segment, the tarsus.

A table of comparative measurements of the two species is given below.

The Pleistocene form of *Æchmophorus* could scarcely be looked upon as a progenitor of the Recent species, even if the latter were absent from the Fossil Lake Beds. The differences displayed by *Æ. lucasi* are such as to indicate a greater degree of specialization for the semi-aquatic life. The two seem rather to have been of common origin and during the Pleistocene time perhaps of about equal abundance. The less specialized and more distinctly adaptive form has persisted until the present while the closely approximated phylogenetic twig became extinct.

The extent to which the loss of this form was due to its weakness in migration is an interesting subject for speculation. The existing *Æ. occidentalis* is a regularly migratory form, individuals of which probably pass over a distance of twenty to thirty degrees of latitude. Though far from conclusive, the indications from Fossil Lake in Oregon and from the Pleistocene fauna of Rancho La Brea in California suggest that the climatic changes on the west coast since that time have been in the direction of lower temperatures and decreased humidity.[5] The latter condition would bring about greater extremes of climate, and make more imperative the migratory movements of birds, and especially of a form so intimately dependent upon aquatic fauna, including invertebrates, for its food. The minute fresh-water plankton forms are very delicately responsive to variations of light and of temperature.[6] The larger arthropods and the vertebrates which might serve as food for grebes would respond less delicately than the microscopic forms, yet their intimate dependence upon the microplankton would cause their numbers to rise and fall with the major fluctuations of the latter.

The intermittant nature of smaller lakes incident upon a decreased humidity and the more marked seasonal variation in food supply can readily be imagined to have rendered imperative a degree of migratory activity to which *Æchmophorus lucasi* was less able to respond than was its contemporary form, the persistent *Æ. occidentalis.*

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[5] Miller, L. H., Univ. Calif. Publ. Bull. Dept. Geol., 5, nos. 19 and 30. 1910.

[6] Kofoid, C. A., Bull. Ill. State Lab. of Nat. Hist., 8, art. 1, p. 291. 1908.

Femur	*Æchmophorus occidentalis* Recent	*Æchmophorus lucasi* Average of Five Specimens	Maximum	Type
Total length	43.8 mm.	47.7	49.0	48.0
Transverse diameter through proximal end	13.8	14.5	15.0	14.6
Transverse diameter through condyles	14.4	15.3	15.5	15.3
Transverse diameter through center of shaft	5.0	6.1	6.7	6.2
Sagittal diameter through center of shaft	6.0	7.4	7.6	7.5

Tarsus	*Æ. occidentalis*	Cotype of *Æ. lucasi*
Length from intercotylar tuberosity to external trochlea	70.0 mm.	74.6
Sagittal diameter through head region	14.1	13.8
Transverse diameter through head region	12.2	12.0
Transverse diameter through trochlea	8.0	8.3
Least transverse diameter of shaft	3.3	35.0

Coracoid	*Æ. occidentalis*	Cotype of *Æ. lucasi*
Total length on inner border	44.5 mm.	47.7
Least transverse diameter of shaft	4.1	3.8

ERISMATURA JAMAICENSIS (GMELIN).

This ubiquitous little duck seems to have been rare in the Pleistocene fauna of the Fossil Lake region. It is not mentioned in Schuffeldt's report on the extensive collections examined by him. It is represented in the collection from Fossil Lake by a single bone, a perfect tarsus.

The specimen at hand corresponds perfectly in every respect with the corresponding bone of a Recent specimen from the California Museum of Vertebrate Zoology.

The fact that this species is very much at home at present over practically the whole of North America suggests a species in the prime of its vitality. Its rarity in the Pleistocene collections suggests that it is either a comparatively young species, or else, having been but recently added to our fauna from without it has, like some ill-advised introductions by the hand of man, responded to a release from limiting environment and spread over the land to possess it.

CIRCUS HUDSONIUS (LINNAEUS).

This third addition to the known avifauna of the Fossil Lake Beds is also represented by a single tarsus. The specimen was identified as *C. hudsonius* by Lucas, and the determination is verified by the writer through comparison with the same bone from a large female specimen of that species. The Fossil Lake specimen is appreciably smaller, but shows no differences not readily accounted for through difference in sex.

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THE GEOMORPHOGENY OF THE SIERRA NEVADA NORTHEAST OF LAKE TAHOE

BY

JOHN A. REID

BERKELEY
THE UNIVERSITY PRESS

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BY

JOHN A. REID

Editor's Note.—John A. Reid died on July 4, 1909. As a candidate for the degree of doctor of philosophy in the University of California he had chosen for his thesis the study of the structure of the Sierra Nevada northeast of Lake Tahoe, and at the time of his death left a manuscript setting forth the results of his investigations. The manuscript was nearly ready for the printer, but some details were lacking; it was his evident intention to supplement it in some parts, rearrange it in others, and to make some illustrative sectional drawings. I had been in consultation with him during the progress of his work, and had once visited the field in his company and there discussed various points with him. After his death his widow sent the manuscript to me for revision, and it has been my sad pleasure to perform this service for my departed friend. When the geological history of the Sierra Nevada is finally written, this paper of Reid's will occupy the important place always given in science to the pioneer who breaks the way to new truth. I know of no paper in recent years dealing with mountain structure that shows so much ability and insight in the interpretation of complicated faulting and its expression in geomorphy as the one here presented.—A. C. L.

CONTENTS.

INTRODUCTION.

There exist in that portion of the Sierra Nevada northeast of Lake Tahoe several very peculiar geomorphic features that call for explanation. Of these Little Valley, an elevated longitudinal valley within the range west of Washoe Lake, is at first glance

the most important. A geological inquiry into its genesis became the stepping stone to the study of the geomorphogeny of the surrounding part of the Sierra. The work is yet necessarily incomplete, for the subject is one of vast complexity and almost infinite detail, yet sufficient has been accomplished to establish a few fundamental relations between the various geomorphic and physiographic elements. It is believed that a definite basis has been constructed for future work in deciphering the history of the Sierra Nevada in Professor Lawson's recent papers,[1] and the facts presented in this paper are offered as a small contribution to extend our knowledge of the Snowy Range.[2]

This paper aims primarily to present the larger details of the geomorphogeny of the area examined. The study has led naturally and unavoidably into the consideration of other details of the history of the Sierra Nevada, and outlines of these will be sketched as completely as possible, in order to facilitate future work. The petrographic investigation of the rocks of the roof of the Great Sierran batholith is a most important subject for study. The correlation of the various Tertiary extrusives with one another, and with the different orogenic movements of the range is likewise a most fascinating and important field for research. Further than these there is the history of the Carson River, with that of the Truckee further north; the study of the evolution of the Tahoe moat and the history of the lake basin proper; the glaciation of this portion of the range; and smaller details too numerous to mention.

The area covered, in part carefully and in part by hurried reconnaissance, constitutes the southwest portion of the Carson quadrangle of the United States Geological Survey lying between longitudes 119°40′ and 120°, and between latitudes 39° and 39°20′ (see map, plate 28). There is thus embraced a por-

[1] Andrew C. Lawson, "The Geomorphogeny of the Upper Kern Basin," Univ. Calif. Publ. Bull. Dept. Geol., 3, 1904, no. 15; and "The Geomorphogeny of the Tehachapi Valley System," ibid., 4, 1906, no. 19.

[2] The writer's first visit to Little Valley was made in September, 1904. A complete geologic survey of the whole area was planned, but had to be abandoned. The first notes on the subject were presented to the Cordilleran Section of the Geological Society of America in December, 1904. Since then further work has been done, and the present paper is the result. The writer desires to express his sincere obligation to Professor A. C. Lawson for his critical reading of the first notes.

tion of the great fault zone of the Sierra Nevada, the eastern portion of the Lake Tahoe moat, and the western flanks of the Virginia and Pine Nut ranges. Brief mention will be made of a few localities off the map, as Mt. Rose, four miles northwest of Slide Mountain, and the Truckee meadows west of Reno. Some areal mapping has been done about Steamboat Springs just north of the limits of the map, but the results are unnecessary in the present paper.

PETROGRAPHY AND GEOLOGICAL RELATIONSHIPS.

The number of rock species in the area is not great. They play a small part in giving expression to the geomorphy but are very important, particularly the later ones, in their relations to the many orogenic movements which have occurred.

Following the recognized classification, the rocks of the region are: (See map, pl. 28).

1. The Bedrock Complex, consisting of granitic and schistose rocks.

2. The Superjacent Series, consisting of volcanic intrusives and extrusives, lake beds, river gravels, and recent alluvium.

THE BEDROCK COMPLEX.

The plutonic member of the older rocks is intrusive into and hence younger than, the schistose rocks, and makes up much the larger part of the exposed rock surface of the area. The schists occur in isolated patches, two of considerable extent, over the area. The size of these patches increases from north to south. They represent the residual fragments of the roof of the great Sierran batholith. Beyond the limits of the mapped area the schists extend southward and occur also across Lake Tahoe, on Mt. Tallac and southward. Southeast of the lake erosion seems to have removed a larger proportion of them, due probably to the greater elevation of the range in this locality. North of the area shown on the map a large part of the hill south of Steamboat Springs is composed of the schists, the granite being there intrusive into them. A still larger area is found making up the most of Peavine Mountain, five miles northwest of Reno. West of Lake Tahoe, on the Truckee quadrangle, these rocks are in

relatively much less amount. In the Carson area, just west of Lakeview, there are many small isolated spots, the smallest having a diameter of only ten yards. The largest areas are little more than a veneer over the granite, so that it is evident that the work of removing the roof of the granite is nearly completed. The smaller areas owe their preservation in large part to the fact that they are slightly sunken in the crystalline rock.

Granodiorite.—The petrography of the intrusive plutonic is in itself a complex chapter in the geology of the region. There is much variation in composition, both chemical and physical. Wherever a contact is exposed, the crystalline rock is intrusive into the older schists and the several facies are therefore regarded as merely component parts of the one great batholith, even though physical connection cannot be found. Chemically, there is a range from the granite of Steamboat Springs, described by Becker,[3] to a rather basic granodiorite or diorite, developed in certain localities along the east flank of the Sierra Nevada. In general the plutonic is probably best classed as a granodiorite, although some areas might well be placed with the quartz monzonites. Lindgren's description of the rock on the Truckee area covers the main features. Hornblende in well-formed prisms, often 2 cm. long, is quite common in the Carson area, particularly near the irruptive contacts with the overlying schists. Biotite, in grains up to 5 mm. in diameter, is usually in much less amount than the other dark constituent. The orthoclase is always present in larger grains than the plagioclase, and not very much less in amount. The grain normally is coarse. The quartz occurs from a small percentage up to 30%. There are two spots where local variation is extreme, one a few miles north of Franktown, and the other north of Carson. Here the grain changes in the distance of a few inches from fine to coarse; chemically within the same distance an acid granite exists next a basic diorite. In some small spots the rock is a coarse-grained biotite granite; in others, nearly no quartz nor biotite are to be found. Frequently the normal rock exhibits dike-like areas of fine grained acid diorite or quartz diorite, with possible flow de-

[3] G. F. Becker, "The Geology of the Quicksilver Deposits of the Pacific Slope," United States Geological Survey, Mon. xiii, 1888, pp. 141-3.

lineated by lines of dark-colored minerals. The whole was evidently in a state of great movement and circulation just previous to the time of solidification. Titanite and magnetite are the important accessory constituents, both in an unusually large amount. Titanite is commonest near the metamorphic contacts, where the yellow crystals invariably attract the eye. Magnetite is usually found in the hornblende crystals, and averages probably nearly 2% of the whole. Quite a few tons of magnetite sand can be found on the eastern beaches of Lake Tahoe near Glenbrook. Aplitic and pegmatitic dikes of prevailing pink tint are very common throughout the granitic mass.

In some small areas these dikes are so common that the surface is composed almost entirely of their fragments. Tourmaline is common in the pegmatite veins. Quartzose phases of the pegmatites are likewise frequently found, small fragments of which look, upon casual inspection, like ordinary vein quartz. The granodiorite contains a large volume of basic inclusions, a further reference to which will be made.

Schists.—Petrographically the schists cover a wide range. Lindgren[4] describes those of the Truckee quadrangle as "sedimentary rocks metamorphosed to hornfels, quartzites, and knotty schists." This character applies well to certain portions of the Carson area, best near Lakeview, east and west. But beside the altered sediment there is a great development of metamorphosed volcanic rocks, including flows and tuffs. These are best exposed in the large area west of Carson, and are chiefly andesitic in character. Those areas immediately north and south of Carson are likewise metamorphic andesite, but in the spur from the Virginia Range south of Washoe Lake the sedimentary character again is in evidence. On Prison Hill a large amount of metamorphic agglomerate shows near the contact with granite, here a fault line. On Mt. Tallac, metamorphic andesites are again in large amount. Peavine Mountain, near Reno, is noteworthy in showing a large amount of altered acid volcanics. In all areas the old sedimentaries are characterized by a well-developed schistosity; the volcanics by little or, at times, none. The schists are usually hornblendic, from dark blue-gray to black in color,

[4] W. Lindgren, Truckee Folio, United States Geological Survey Text.

and of fine grain. No limestone as such has been recognized in the area examined. On the east slopes of Mt. Davidson, in the underground workings of the mines at the north end of the Comstock lode,[5] limestone was cut. This probably belongs with the metamorphic rocks to the west. At Lakeview Hill and north of Carson there are evidences of limestone in the great development of lime-bearing contact minerals. The planes of schistosity are nearly, if not quite, coincident with the bedding. The dip and strike are in all directions and angles, due to the plutonic intrusive. On Lakeview Hill the schists lie approximately parallel to their contact with the granite, striking about N 32° E and dipping SE 68°. Where the schists are not greatly disturbed and sunken into the plutonic rock, the schistosity is usually roughly parallel to the contact, as at Lakeview Hill. In the very small area west of Lakeview the schists stand about vertical, striking roughly north and south. West of Carson, from Kings Cañon up, the lowest rocks are schists, standing vertical and striking parallel to the cañon; the higher rocks are andesitic flows and tuffs striking northeast and southwest, and dipping gently to the northwest. The age of the metamorphic rocks is referred to the Jura-trias, in keeping with Lindgren's conclusions in the Truckee quadrangle. That area centering about Ward's Peak, west of Tahoe City, is composed of rocks apparently identical with those of the Nevada region. Lindgren has presumably classed the Ward's Peak area with the Sailor Cañon formation, of unquestionable Jura-trias age. From the similar character, areal distribution, and relationship to the granite, it appears probable that the various isolated patches of schists are to be correlated with one another and with the metamorphic rocks west and southwest of Lake Tahoe, and originally forming the complete roof of the great batholith of the range.

The Irruptive Contact.—The irruptive contact of the granite and metamorphic rocks presents another important and interesting problem. The best exposure of this contact is in the railroad cut, on Lakeview Hill. A second good, though small, exposure, is in the hills north of Carson. The other exposures are not so promising for further study. At Lakeview Hill the con-

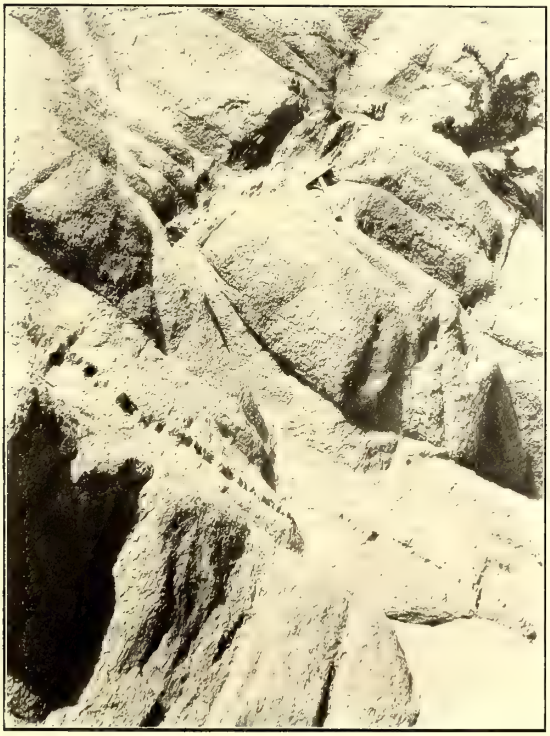
[5] Becker, U. S. G. S. Mon., III.

tact strikes nearly east and west and dips south at rather a high angle. The actual contact is a very irregular surface, for the schists are badly broken and invaded in all directions by apophyses of the plutonic rock. (See pl. 19A). The intrusions into the schists are of three kinds and probably of three ages. The oldest are the small finger-like portions of the main mass of the granodiorite. These are commonly more basic than the normal facies. Next come large dike-like intrusions of an acid phase of the granitic magma, pinkish in color and almost free from dark constituents. Lastly come the pegmatite dikes, that cut all other rocks. After the intrusion of the last, much further squeezing occurred, the whole complex being more or less plastic. The result of this is seen in the folding of the pegmatite dikes.

In the Lakeview cut much absorption of the schist by the crystalline rock is evident. A number of fragments of the older rock of the general shape of huge eggs were taken out by the writer, and exhibit well-marked zones of metamorphism from outside to center. Also, schist fragments occur many feet from the actual contact. (See pl. 19B). Nor is this all. The presence of basic inclusions in the granodiorite has been noted. Both at Lakeview and north of Carson actual schist fragments can be traced into inclusions identical to the unaided eye with the basic inclusions far distant from undoubted schist areas. It would be unwarrantable to assume without careful petrographic study the derivations from schist of many basic inclusions in the granite, but there can be no doubt that some have this mode of genesis. It is to be noted further, however, that frequently the basic inclusions have a form entirely compatible with this idea, the cross-sections showing uniform width with usually much greater length. Some show the roughly rhombic outline of the jointed schist blocks.

At Lakeview Hill the schists above the contact are characterized by a great amount of lime-garnet and epidote. The whole mass of the rock is frequently entirely composed of one or both of these minerals. The three important contact minerals are garnet, epidote and hornblende. North of Carson similar results are evident, but in the altered andesites epidote is the chief contact mineral, developed along cracks and seams. These seams also

A. Contact of granite and schist. Lakeview Hill.



B. Inclusion of schist in granite. Lakeview Hill.

show silicification, or better, metasomatic replacement of the original rock by quartz and epidote. The Lakeview rocks were originally probably limestone, perhaps somewhat impure, yet needing the addition of silica from extraneous sources for the formation of the large quantity of lime-bearing silicates. The mineralogy and petrography of the whole metamorphic area needs and deserves attention. There is a widespread dissemination of chalcopyrite and bornite, which has caused considerable prospecting west of Carson. Free gold is also found near Kings Cañon in the schists, and seems to be connected with the granitic intrusion and metasomatic changes in the older rocks.

The Roof of the Batholith.—The irruptive contact is noted for a number of springs, particularly at Cemetary Hill, a mile north of Carson, and at the schist area further north, east of Washoe Lake. This surface, though locally irregular, yet shows in its larger form nearly a plain, with occasional blocks sunk into the granodiorite. At present most of the fragments of the old roof of the batholith are more nearly horizontal than vertical, some quite so. The variations to vertical or highly inclined can be traced to deformation of crust blocks. It is probable that the original contact surface lay nearly horizontal in this area, with, of course, sharp local modifications. Contacts now dip toward the valleys away from the summits. North of Carson the dip is southerly; west of the town it is easterly. The Lakeview Hill block shows a highly inclined contact plane with a southerly dip, placing this block strictly with the Virginia Range rather than with the Sierra.

The areas of metamorphics at Genoa Peak and west of Carson show a very gentle easterly dip of the contact. Near Glenbrook the dip is westerly toward the lake.

The Superjacent Series.

River Gravels.—The oldest member of the later rocks present in the area consists of the gravels of a Neocene river channel lying between Lake Tahoe and Washoe Valley, with traces in the Virginia Range. This channel presents one of the many interesting features of the region, and because it crosses completely the great fault zone, it possesses an additional value in decipher-

ing the diastrophic record. Unlike the Tertiary river gravels of the western slope of the Sierra Nevada, practically no work of mining development has been done in this eastern channel, though gold is found in some amount. Hence many of the characteristics must await a more favorable time for their determination. The maximum width of the gravels is estimated to be about 300 yards, but excessive faulting masks the dimension. The depths where best preserved is at least 500 feet, and may be much more, for exact data is not to be obtained. The gravels range from coarse, with boulders a foot in diameter, to fine gravel that would pass a 1-inch screen. The form of all is very rounded and indicates a long passage in the waters of the old river. Thus far search has revealed worn fragments chiefly of the old metamorphic rocks, with some porphyritic boulders that may belong to the same Jura-trias formation, or may be derived from the diabase-porphyrite series. Gabbro-like rocks and granodiorite are also found, but are badly decomposed. Of the undoubted metamorphic rocks quartzite boulders, often a quartzite breccia, are in great abundance. Schists and hornfels also are present. Near Lakeview there is a large amount of nearly pure iron ore in that portion of the channel mined years ago. Both magnetite and hematite are present, in boulders up to a foot in diameter. Some little quartz in veinlets is present. Crystalline structure is well developed, and causes the worn surface to exhibit complex etched figures. A few small boulders of a schistose rock are found containing hematite and magnetite in small stringers and irregular masses. The matrix is amphibolitic, but very fine grained. The source of the iron ore is, therefore, probably from the contact zone of the granodiorite and schists. The gold is fairly coarse, averaging the size of grains of wheat. The writer has been informed by those who have been interested in the mining of the gravels near Franktown that about $160,000 has been extracted in a crude way. The gravels are partly covered by later lavas. It is yet impossible to determine absolutely the direction of flow of this old river. The only criterion now of much value is the relation of the composition of the gravels to the rocks of the surrounding country. The metamorphic areas yet in evidence show much quartzite west of Lake Tahoe,

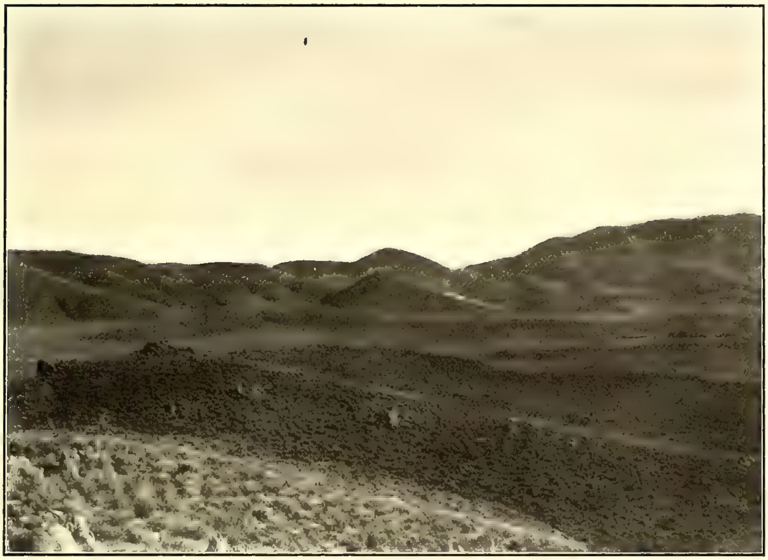
but none on the east side. Gabbro at present exists only southwest of Tahoe City. The metamorphic andesites correspond with those of the Mt. Tallac area and the area west of Carson. The porphyritic boulders are derived possibly from the diabase-porphyrite area to the west. From what little is known of the whole of the gravels, it can be stated that they have closest relations with the rocks of the west and southwest. This conclusion, if true, means that the river flowed eastward from a divide some distance west of Lake Tahoe. Possible evidence of eastward flow is also found in the gorge-like portion of the old channel on the fault-block just east of Lake Tahoe, now filled with rhyolite capping the gravels. East of Washoe Lake, in the Virginia Range, scattered boulders have been found in a few places, and a bed of gravel over an acre in extent is found north of Carson at the point where a wet-weather stream debouches upon Eagle Valley. All these probably represent transposed remnants of the old river channel. Nothing definite can be stated for the area further east.

Volcanics.—The volcanic rocks are of various types and ages. The relative ages are for most of the species yet in doubt, for but few contacts are visible. A glance at the map will make the reason for this clear. In the Sierra Nevada proper the volcanics exist only in isolated patches. The two important members of this group are rhyolite and andesite. Both are found capping the river gravels, yet nowhere come into contact. The texture of the various residual spots of andesite is not everywhere the same, and sufficient variation exists to justify the belief that there is some difference in age. This, however, is yet an open question. Northeast of Glenbrook there are dike-like occurrences of andesite within the large area of the same rock. South of Glenbrook, just beyond the edge of the andesite flow, occurs a circular neck of andesitic rock rising vertically out of the granite that is probably of earlier age than the flow. West of Lake Tahoe Lindgren describes the rhyolite below the andesite. In the Truckee Cañon east of Reno, as characteristic of the Virginia Range, the andesite is on top of the rhyolite. Hence for the present the greater age of the rhyolite near Carson will be assumed.

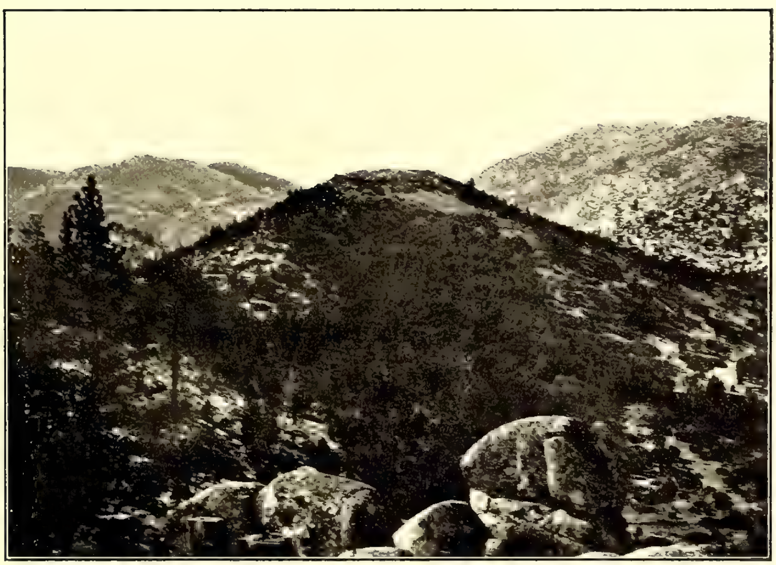
Rhyolite.—The rhyolite is of constant characteristics. It is a porphyritic rock, with well-developed phenocrysts of quartz, glassy feldspar, and flakes of brown biotite, in a white ground-mass weathering to pink. A tendency to vescicular texture is frequently observed. The lower portion of this volcanic rock is often a breccia, as seen capping the river gravels south of Franktown. No rhyolitic dikes or vents of any kind have been noted.

Pitchstone.—An acid pitchstone occurs in a few small areas associated with rhyolite. One of these is in the low hills south of Franktown. Here the glassy rock occurs as a small oval spot a few hundred feet in diameter on the flat top of the hill with the longer axis east and west. A dike extends from the larger mass several hundred yards northerly down the cañon. Three other oval patches of this rock occur in the low spur of the Virginia Range north of Carson. These are shown rather diagrammatically on the map (pl. 28) due to their small size. The longer axis of these small areas is always easterly and westerly, and appear to make a line of movement in this direction. No detailed investigation has been made of this rock, but because of its association with only the rhyolite and the fact that it shows a few phenocrysts of glassy feldspar in a light colored vitreous ground-mass, it is regarded as genetically connected with the rhyolite. It is probably but little later in age.

Andesite.—The larger part of the andesite is a hornblende bearing rock, but the grain varies from very fine to porphyritic, with the phenocrysts of hornblende 1 cm. in length. The color is a dark gray, weathering light gray. A slight tendency to vescicular texture is at times noted, as in Little Valley. This rock is found in a great number of dikes, in a few cones, and in a number of small residual patches, or in the granite, representing once much larger flows. The dikes usually have a north-south or north-northeast—south-southwest strike, but a few show an east-west direction. They are exceedingly common throughout the granite area, but on account of their small size and complex displacement by faults only the largest and most important one, that in Lakeview Hill, is mapped. A few feet east of the rhyolite area northeast of Marlett Peak is a small four-foot dike of andesitic breccia or agglomerate. Unfortu-



A. Old andesitic cone, looking north from Carson.



B. Andesitic cone, southwest of Washoe Valley.

nately it is nowhere in contact with the rhyolite. In the north part of Little Valley, near the head of the cañon of Franktown Creek, is a small area of the typical hornblende andesite, with which is associated some breccia similar to that of the small dike to the south. A correlation is made for this reason. A few other dikes associated with cones exist. The andesitic cones are interesting features of the geology. There are two well-formed cones in the area, the larger directly north of Carson, and the smaller a mile west of the southwest corner of Washoe Valley. The andesite in both these cones is more massive than the rock in the dikes, and frequently show well-developed joints. The petrography of the andesites yet needs investigation. The cone north of Carson (pl. 20A) is held to be such because (1) of its perfect conical form and (2) the contact between the volcanic and surrounding schist is marked by much breaking and distortion of the latter rock, its intense metamorphism and vertical dip facing the cone. Near the summit of the cone joints are well shown and result in the formation of rough hexagonal columns lying with their axis nearly horizontal about N 55° W. The cone west of Washoe Valley (pl. 20B) is held to be such on account of its form and the existence of a few radial dikes in the southwestern flank. Some of these dikes are peculiar in their being composed of andesite full of angular fragments of granodiorite. One dike nearest the cone has a well-developed jointage (pl. 21A). Of the residuals of the andesitic flows little further need be stated. They all appear to be connected either with dikes or the cones.

A second well-marked variety of andesite occurs in the area just east of Glenbrook. A large part of this appears in the field to be quite similar to the andesite already described, but part is very different. This latter rock is microscopically identical with Becker's "later hornblende andesite" at Virginia City. It is a coarse-grained rock with phenocrysts of mica, hornblende and feldspar in a purplish gray ground-mass. On the road east of Glenbrook it has the appearance and character of dikes intruded into the other andesite. Not sufficient field work was done to settle this point definitely. Microscopically the two andesites are quite similar to Becker's earlier and later hornblende andesites at Virginia City.

Basalt.—The single area of rock mapped as basalt lies north of Carson, and extends from the apex of a high ridge at an elevation of 6,750 feet, to the valley near Empire. The flow lies on rhyolite. The flow-planes strike northwest-southeast, and dip southwest about 45°. In the field the basalt looks much like that at Steamboat Springs, described by Becker. The rock is in part massive and in part, near the top, very vescicular. Traces of cindery and scoriaceous facies are present. The soil from the basalt is intensely brick-red. A large portion of the top of the flow near the valley slopes gradually downward and is fairly unbroken. But as the higher slopes are reached much breaking of the surface has occurred. The south face of the highest point covered by the lava is very steep and covered with a thick coating of angular fragments. The form of this pile is that of a large D, giving the name D Mountain to the summit. It is plainly in evidence from Carson.

Other Rocks.—The remaining rocks of the Superjacent Series consist of lake beds, recent river gravels, and alluvium. These would be of little importance were it not for the fact that they are of value in deciphering the later geomorphy of the region. The Carson lake beds, famed for its footprints, are little if at all disturbed. Beds in Washoe Valley are tilted, however, as are those near Reno. The lake deposits and beaches surrounding Lake Tahoe offer a yet untouched field, and their bearing upon later crustal movements is evident. The terraces of the Carson River within the mapped area, and those of the Truckee near Reno, are likewise important. All will be discussed in the proper place.

Relative Age of the Superjacent Series.

Because of the bearing upon the series of orogenic disturbances, the relative age of the later rocks, as far as can be determined, needs mention. That period in the growth of the range characterized by the various Tertiary eruptions was also a time of intense diastrophism. The writer desires to urge the use and value of these volcanic rocks in the study of this portion of the range history. It is believed that a definite correlation between the orogenic movements and lava flows over all the

region can be established. If this be done, a great step in advance toward unraveling the complete geological history of the Sierra Nevada will have been taken.

The earliest lava flow about which we have definite evidence is the rhyolite. This capped the old river gravels before a large amount of the faulting had occurred. The lowest parts of the rhyolite are breccias. Above and next in age is the pitchstone, in the few small patches noted. Andesite, perhaps as an earlier and a later flow, is next in the series, although some andesite may antedate the rhyolite. Basalt represents the last volcanic activity in the region. Of the absolute age of these lavas we as yet know little. Even the relation of the basalt to the Carson lake beds is not known by direct evidence. The lake beds are entirely granitic in the valley below the basalt, and the flow is probably later and therefore of late Quaternary age.

INFLUENCE OF ROCKS UPON THE GEOMORPHY.

Before proceeding to a consideration of the geomorphy it becomes necessary to ascertain the influence of the various tectonic units upon the land form. The main elements of the geomorphy are due to causes that have no direct ascertainable relation to the rocks of the Superjacent Series. In the Sierra Nevada these later rocks have at the most a slightly modifying effect upon the form. The chief forces that have acted upon the range are those of the atmosphere and those of diastrophism. The volcanics are removed by erosion so rapidly compared with the granodiorite and schist that they have left no great effects upon the topography due to their original forms. Diastrophic movements have been most severe since the volcanic period and have faulted all rocks alike. Hence we are chiefly concerned with the Bedrock Complex in the present connection.

Joints.—The granodiorite and schist are intricately jointed. The joints are persistent through both rocks irrespective of their physical differences (see pl. 21B) and are always along planes. Their position bears no relation to the surface, either present or ancient. This statement is based both on observation and on the nature of the physiographic form. Upon the old erosional surface and the more recent fault-scarps the faults could have

exercised at most but a very minor directive control. The position of the joints in Lakeview Hill is well shown in plate 21B, but no precise general statements can yet be made concerning their position throughout the region. The strongest jointage seems to be that in a north-south direction, with two other sets at right angles, the latter varying in position at different places. This variation seems to be due to the excessive displacement of crust blocks. The joints appear to be due to stresses set up in the mass when at great depth, becoming planes of actual disruption upon the removal of pressure of superincumbent rock under the activity of atmospheric forces. On the old erosional surface the schists are much more minutely fractured than the granite. This is due probably to the greater changes in stress they have experienced.

Weathering.—Upon the formation of the many fault-scarps of the region the weathering of the rocks can have had no control. But an investigation of the mature erosional features present upon the summits of the various ridges necessitates a knowledge of differential weathering of the older rocks. The results of atmospheric attack upon the younger rocks are of a much less order of magnitude than those of diastrophism. The drainage lines are almost invariably consequent. Of the Bedrock Complex the granodiorite, with the exception of the contact zone and the few small areas noted for the variations in the crystalline mass, presents a quite uniform resistance to disintegration and erosion. The fault-scarps show fresh rock within a few feet of the surface, except at the buried bases or upon the older planes of dislocation. On the ancient surface of erosion disintegration has taken place to considerable depth and fresh rock in place fails to show. Such level areas show many boulders of disintegration lying upon a base of coarse granite sand and "rotten" rock. The only spots in the granite that project above the general level are those characterized by a large number of pegmatite dikes. Such spots, however, are elevated but a few feet, as the crumbling of the normal rock removes the support from thin pegmatite intrusions and allows them to break down. But the schists also form part of the surface of erosion yet remaining. When present the ancient peneplain passes from the one rock to the

A. Columnar structure west of cone shown in plate 20B.

B. Joints traversing granite and schist. Lakeview Hill.

other unaffected by the change. No residuals of the metamorphic strata project up above the general level. Minor irregularities do exist, and usually the small schist areas are a few feet above the granodiorite. The reason is not hard to find. Were neither rock jointed and therefore open to atmospheric agencies except through pore spaces, the granodiorite would be disintegrated and eroded much the faster. On the other hand, were the two rocks equally resistant to decomposition and disintegration, the schist would disappear more rapidly, due to its condition of excessive jointing and fracturing. The actual result of these two sets of conditions is a mean. The rocks are about equal in their ability to withstand disintegrating forces. As a further result, the granodiorite on the old level surfaces presents its usual features of deep sandy soil covered with boulders of rotten rock, while the schist has a rough appearance, and is covered with small, sharp, angular fragments, the larger of which commonly have centers of fresh material. The larger schist areas that form part of the old erosional plain show some soil, the top of which is covered by a layer of angular schist fragments of small and remarkably uniform size. This latter condition is a natural result of the breaking down of the schists on a level or nearly level surface, where the disintegration proceeds faster than the erosion by running water. The difference between this and the appearance of the small schist residuals is significant. Here the support of granite material is carried away, with resultant coarse disintegration of the metamorphic rock. This allows all fine sandy material to be removed as fast as formed to the slightly lower surrounding granodiorite, and leaves the sharp jagged edges of joint fragments uncovered. A further result of the different mode of weathering between the plutonic and the schistose rocks is found in the appearance of the slopes due to faulting. The granodiorite tends to maintain its sharply cut outlines, even though quite deeply disintegrated. The schist, on the contrary, because of its intense fracturing, usually presents more rounded slopes and smoother lines. The maximum effect of this variation in resistance to atmospheric forces is thus one that but slightly modifies some of the lesser physiographic forms.

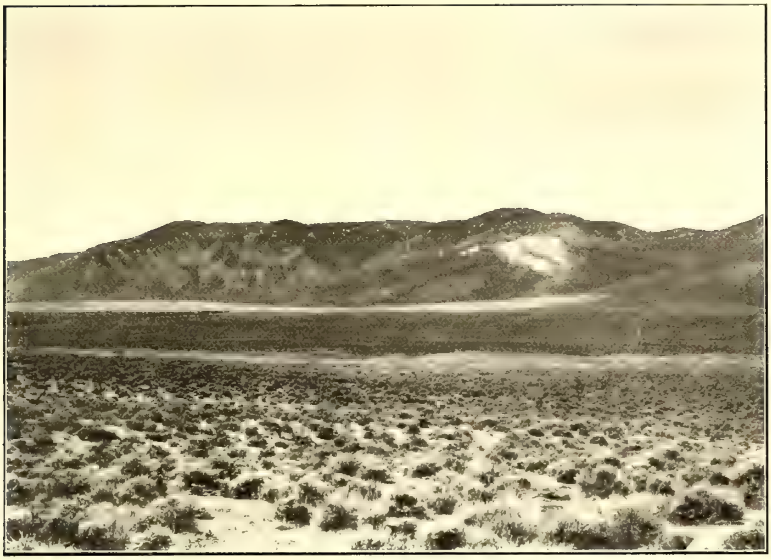
TOPOGRAPHIC DIVISIONS.

In this area there are three larger topographic divisions or belts, running north and south. From west to east these are (1) the eastern portion of the Sierra Nevada; (2) the level valleys at the east base of the Sierra; (3) the western portion of the Virginia and Pine Nut ranges. The first can be divided into the Tahoe moat, or down-dropped earth-block, on the west, and the high ridge on the east. The depression caused by the sunken block is occupied by the lake west of Carson, and by andesitic flows further north. This easternmost part of the Sierra Nevada is call by Lindgren[6] the Carson Range, and is in this latitude the east crest of the Sierra Nevada proper. It is characterized by the two highest peaks of the region, Mt. Rose and Freels Peak, respectively, at the northeast and southeast corners of Lake Tahoe. Both mountains rise nearly 11,000 feet above sea-level.

From north to south in the area mapped, the Carson Range is divisible into three parts. The northern part, bounded on the south by an east-west line through the south end of Lake Washoe, consists of a single high ridge with a lesser one just east, both with straight, simple slopes east and west. The southern part, bounded on the north by an east-west line through Glenbrook, is composed of a single ridge with steep slopes in the east and a gentle one to the west. The central part is made up of a medley of comparatively small longitudinal ridges and valleys quite different from the others.

The second topographic division is composed of the three connected valleys: Washoe Valley on the north, Carson Valley on the south, and Eagle Valley in the center. Each valley is opposite one of the three topographic divisions of the Carson Range. Eagle Valley is the smallest of the valleys, east of the widest of the three topographic divisions of the Carson Range. Carson and Eagle valleys are separated by a low divide opposite Prison Hill, inappreciable to a casual glance. Eagle Valley is separated from Washoe Valley by a low ridge connecting the Virginia Range with the foothills of the Sierra. Washoe Valley

[6] Truckee Folio, U. S. G. S.



A. Genoa Plateau.

B. Erosional surface east of Marlett Peak.

on the north is terminated by another low ridge connecting the same two ranges.

The third large topographic division is composed of the western flanks of the Virginia and Pine Nut ranges, and is of little importance in the present paper. These two ranges are separated by the gorge of the Carson River and the low area adjacent.

To the south of the Carson quadrangle the Pine Nut Range joins the Sierra Nevada and is therefore genetically a portion of the large Sierra.

GEOMORPHY.

The geomorphic features of the area mapped are in the main clear and sharply defined. Most prominent are the many fault-scarps in the mountains, descending from the highest ridge crests to the valleys. The level valleys themselves, meeting the steeply rising mountains at sharp angles, provoke comment from those unaccustomed to the region. But the third type of physiographic form is not seen unless one knows where and how to look. From low points in the valleys there is a wealth of suggestion to the physiographer in the flat-topped appearance of many of the highest ridges (pl. 22A). This suggestiveness merges into a reality if one ascends the steep fault-slopes to emerge at the summit upon a land of topographic old age. The transition in some places from the sheer fault-scarps to the flat ridge tops is so abrupt as to be almost startling. There are thus three distinct geomorphic zones, each very different from the other. Upon many of the ridge tops throughout the region mapped occur small areas a mile or two in diameter that present the appearance of an old eroded surface, a peneplain. Plate 22B shows that one near Marlett Peak. In a few places traces of the same surface are found little above the level of the Nevada valleys. Each separate level area caps a fault-block, and therefore, as each block has moved differently with respect to those adjoining, there are marked differences of elevation between the residuals of what was undoubtedly a continuous peneplain before the uplift of the Sierra in Pliocene time. The old surface may now be regarded as a broken and dislocated plateau.

The plateau residuals are commonly isolated, but on the large schist area west of Carson the ancient plain descends to the valley in a series of steps. Below the plateau remnants the fault-scarps, some almost unaltered and some partly degraded, descend to the valley. The zones are thus hypsometric as well as geomorphic. The elevation of the ancient plain ranges from 6,500 feet to 8,300 feet. The zone of the Nevada diastrophic valleys averages about 4,800 feet. The fault zone lies between, bounded above and below by level areas.

Upon more careful examination of the highest or plateau zone, it is found that at a few points low hills rise gently above the surrounding peneplain. These hills are today the important mountain peaks, though rising but a few hundred feet above the ancient plain. They are few in number but important in their bearing upon the geomorphic evolution of the range. Hence, for clearness in discussion and to enable a better coördination to be made with Professor Lawson's geomorphic zones[7] in the Kern basin, they are here placed separately in a summit zone. There are then, in the Carson region four zones: (1) the summit zone, (2) the plateau zone, (3) the fault zone, and (4) the valley zone.

I. The Summit Zone.

The summits rising above the plateau remnants are best represented by Slide Mountain, Marlett Peak and Genoa Peak, that of Marlett being the best example. In the Virginia Range similar elements of the geomorphy exist, and Mt. Davidson appears as a low summit above the plateau to the west. (See pl. 23A). The exact correlation of the Virginia Range plateau with that of the Sierra will do much to elucidate the geologic history of the eastern range and perhaps settle beyond all doubt the question of sequence and relations of the igneous rocks of the Comstock. Here is again touched the correlation of lava flow with orogenic disturbances. The slopes of the summits rising above the plateau are always gentle, whether composed of granitic or schistose rocks. The summits themselves are flat or nearly so, likewise irrespective of the rocks composing them. *A priori,* these elements of the geomorphy might be (1), due to the control by the

[7] Univ. Calif. Pub. Bull. Dept. Geol., 3, p. 307.

A. Davidson Plateau.

B. View west in upper Little Valley, showing "Kernbuts."

roof of the batholith; or, (2), the remnants of an older surface of peneplanation; or, (3), merely monadnocks rising from the ancient plain. The first possibility is of particular interest because Professor Lawson concludes that the level summits of the High Sierra in the Kern River region are due to the form of the under surface of the roof of the Sierra batholith. In the Carson region the crystalline and metamorphic rocks are about equally resistant to attacks of erosional agencies, so that plateaus above base level could not be formed by the removal of a softer rock above a harder. Hence the facts here are in dissonance with the hypothesis of structural control. There are factors that favor such interpretation, however. These are (1) the approximately level upper surface of the granite batholith, and (2) the nearness of the surface to the flat-topped summits. Here the fact enters that Genoa Peak is flat-topped and composed of schist. Were the hypothesis of structural control compatible with the facts, outside the Genoa schist area, the form of this peak and its associates might be explained on the basis of structural control within the mass of the metamorphic rocks. But in the light of the facts of erosion elsewhere noted, this test fails. Hence the idea of structural control upon the formation of flat-topped summits must be abandoned.

The second possibility, that these summits represent an older cycle of erosion than that producing the high plateau, is one difficult to handle with the few facts obtainable. The hypsometric test of like elevations is obviously impossible on account of the excessive faulting. The only remaining criteria of value are (1) similar hypsometric range between plateau and summits; and (2) the form of the summits themselves. If these fail to establish the hypothesis of an erosional surface, the summits must be regarded as mere monadnocks rising above the plateau. If we compare the elevation of the summits above their plateau remnants, we have the following. Slide Mountain rises about 600 feet above the plateau. However, faulting, combined with tilting of the block, makes this figure here uncertain. A second summit occurs about three miles west of Slide Mountain that has about the same elevation, and tends to confirm the figure above. Marlett Peak rises between 500 and 600 feet above its plateau

remnant. Genoa Peak also rises nearly 700 feet above the somewhat dissected plateau remnant upon which it stands. But this peak is clearly in a triangular fault-block which appears to have been elevated relative to the surrounding blocks. The nearby summits, however, are not so situated. The plateau elevation here is about 8,300 feet, and the elevation of the larger summits outside of Genoa Peak is a little over 8,800. The elevation of the plateau remnants is taken in all cases as marked by the striking subsequent stream channels thereupon. The difference in elevations is thus constantly between 500 and 600 feet, irrespective of the nature of the rock. If we assume for the moment the hypothesis of an erosional surface, the possibility of crustal tilting at the time of the uplift initiating a new cycle of erosion must not be overlooked. This places the question upon the broader grounds of the larger elements of range history. So far as the writer knows, the tilting of the range other than that east and west has been inappreciable. This statement does not include the movements of small blocks. If this be so, there is nothing inharmonious between the hypsometric range and a possible old surface peneplanation. The second test adds to the strength of this conception. The summits are characteristically flat-topped, with gently curved slopes connecting the plateau below. A residual hill or monadnock would present a smoothly rounded summit, unless there were a structural control by the differential weathering of the rocks. There has been no such control, so that the idea of monadnocks has little weight. The writer adopts, therefore, the hypothesis of an older erosional surface than the high plateau. This is not in accordance with Professor Lawson's conclusions, but serves to bring into greater relief the need for more investigation.

II. The High Plateau.

The best remnants of the high plateau are near Little Valley. The largest of these is at Marlett Peak, and is a splendidly preserved area. Marlett Lake exists over the site of a down-dropped block of the same surface. One comes into a different land after toiling up the surrounding steep fault-slopes. Traces of this same remnant are found along the ridge that strikes

northwest from Marlett Peak. On the east side of Little Valley more detached areas of the plateau are found. The map fails to express well this geomorphic feature. Furthest north are the areas near Slide Mountain. South of Marlett Lake, Snow Valley Peak is a distinct plateau remnant which owes its unusual height to faulting. The whole slope from this peak to Eagle Valley consists of a plateau remnant faulted into a series of steps, to be described fully in the proper place. Further south lies the Genoa plateau, a striking feature of the landscape from all points of vantage around the lake.

The fact that the separate areas of the high plateau have considerable range in elevation, for instance 6,700 northeast of Little Valley, 8,300 at Genoa Peak, and a little over 9,000 at Slide Mountain, may be urged against their definite correlation. The facts which favor such correlation are: (1) the splendidly preserved character of the plateau; (2) in each particular locality there is but one such surface; (3) the intense faulting of the region is amply sufficient to account for all hypsometric differences; (4) in spite of the fact that all plateau remnants are isolated, the separate areas occur in chain-like arrangement from north to south, and two contiguous portions are separated clearly by a fault with a downthrow of the lower; and lastly (5), the similar characteristics of all the remnants, giving in the field the immediate impression that all are but parts of a single surface of peneplanation. For these reasons it is held that there is represented but one plateau.

Significance of Summits and Plateau.—If one stands upon the summit of Mt. Tallac, upon the shoulder of which occurs a remnant of the high plateau, this old surface is seen to be hypsometrically identical with the larger portions of the Tertiary peneplain that occur to the south sloping down gently to the west, from elevations of 9,000 on the east. Monument Peak and the group of high mountains clustered about Freel Peak, all just south of Genoa Peak, belong to the same zone of high plateaus and summits. Thus Lake Tahoe is surrounded on the south, east and southwest by remnants of the old Tertiary peneplain. There is then possible a correlation between the high plateau zone of the Tahoe area with Lawson's sub-summit plateau in the Upper

Kern region. The summit zone is less obvious in its relationship. If it represent a still older erosional surface, as is adopted for the time, it seemingly finds no homologue in the Kern country. Lindgren has noted the presence of a Cretaceous peneplain on the western slopes of the Sierra, and a correlation may be made with this. The summit upland and the high valley zone are not represented on the area mapped. The former appears to be entirely lacking in this portion of the Sierra Nevada; the latter probably finds its analogue in the high valleys south of Lake Tahoe, of which Faith, Hope and Charity valleys are the best representatives.

III. The Fault Zone.

At the first glance from lower elevations, the Carson region of the Sierra Nevada appears to be entirely an aggregate of granite peaks, whose flanks usually descend precipitously to the level valleys, but at times show gentle rises just above the valleys. The geomorphy wears the air of extreme youth, with no hint of maturity. It is only after one climbs up the steep sides of the range and suddenly enters a country the geomorphic age of which is plainly evident that there is a realization of the complexity of the geomorphogeny. It has been assumed without first adducing proofs that the geomorphic zone below the plateau, composed of the steep slopes and minor details of the topography, is truly a fault zone. That it is such becomes evident upon slight inspection of the map or field. Faulting is immediately recognized by a glance at the old river channel, but the larger part of the zone is in granitic rocks and requires more careful treatment. The features of the zone will first be described, and this will be followed by a discussion of their origin. For the present it is sufficient to state that the larger proofs of the fault zone being such, are (1) the lack of adjustment between high plateau, steep slopes, and level valleys; (2) steep, often but slightly notched granite fault-scarps; and (3) stratigraphic evidence from the plateau schist areas, river gravels and lava flows.

Of all the striking features of the fault zone that of Little Valley, a large, well-developed longitudinal valley, is the most important. This importance is due both to the peculiar trend of the drainage, parallel to the range crest, and to the fact that at

least three distinct periods of faulting and uplift are recorded there. The next most important feature, connected with proofs of the faulting of different ages, is the large number of lesser crust blocks found in every part of the fault zone. Also, there are two other examples of well-developed longitudinal valleys, though their size is very small compared to Little Valley. Lastly a few minor details of topography call for explanation, such as the peculiar floor of the north end of Little Valley.

The analysis of this great fault zone is of vital importance to the history of the evolution of the Sierra Nevada, for by it we can obtain a cross-section, as it were, of the diastrophic movements producing the range, and this knowledge is complementary to that record gained from a study of the west slopes of the Sierra. Furthermore, according to Lindgren, there has been no important post-andesitic faulting along the old fault planes east and west of Lake Tahoe on the Truckee-Carson quadrangle, though further north such movement has been recognized. If this be so, the whole of the Sierra block from the Great Valley to the Carson Range has moved as a unit since the eruption of the andesitic lavas, concentrating the faults in the Carson Range.

In a cross-section of the Sierra through Lake Tahoe there are two summits, separated by the down-dropped block of the Tahoe Moat and Truckee Valley. The west summit forms the Great Western Divide, and is the true axis of the range. The east crest is formed by the Carson Range and carries the two highest peaks of this part of the mountains, Mt. Rose northeast of the lake, and Freels Peak to the southeast. The structure of that portion of the range east of the Great Western Divide is complicated by the down-dropped portion underlying Lake Tahoe, otherwise it might be regarded as a single crust block tilted to the west. A knowledge of the configuration of the floor of Lake Tahoe is greatly needed in this connection. This east-west section across the range can be discussed more fully after an examination of the diastrophic record of the lake. Genetically the Virginia and Pine Nut ranges are a portion of the Sierra Nevada, and records of orogenic movements are preserved not only in the Carson Range but also in the Nevada valleys and ranges.

Detailed Description of the Fault Zone.

The three topographic divisions of the Carson Range have been described. The structure of these in detail will be given, beginning with the central portion, which contains the old river channel and therefore admits of the definite establishment, by means of stratigraphic evidence, of faulting and of the topography due to faulting.

The Carson Area.—The Carson topographic area of the Carson Range is characterized by three quite well defined north-south ridge lines. These are most clearly shown along an east-west section through Marlett Peak. They may be referred to for convenience as the west summit ridge, the east summit ridge, and the low east ridge. The west summit ridge forms the main crest, and bears the two highest points, Snow Valley Peak and Marlett Peak. The east summit ridge rises to elevations nearly as high as the other, and is separated from the main crest by a persistent line of depressions or valleys. The low east ridge rises about 1,500 feet above the Nevada valley, and consists of a series of hills separated by the cross valleys or cañons of the range. The main west summit ridge is complex in detail. On an east west section through Snow Valley Peak this crest is composed of the main peak and two sub-crests to the west. The down-dropped block underlying Marlett Lake also belongs with this topographic division. The east summit ridge and the low east ridge are both comparatively simple. The long slope leading down from the one to the other, however, is again complex, far more than the map indicates. It is strongly characterized by a succession of flats with steep shoulders rising to the west, giving the whole a step-like profile. On this section the slopes rising from Lake Tahoe are steeper than at any other point directly above the water. Huge blocks of granodiorite are continually becoming loosened and roll down to the lake shore. Just northwest of Marlett Peak one can stand nearly 2,500 feet almost directly above the water and obtain a view not to be equalled at any place on the lake. The east-west profile of the Carson Range across this section is quite serrate in character. The three principal ridge lines are persistent, the sub-ridges are not always so. All strike north and south.

At first glance this form of topography is strongly suggestive, if not a proof, of faulting. But the various stream courses hint at much possibly subsequent drainage. Such condition of the streams would account for some of the topographic features, and would render obscure many more. In the Carson area three of the large creeks flow in longitudinal valleys—the upper portion of Franktown Creek; Kings Cañon Creek; and the creek flowing south from Snow Valley Peak. A number of smaller streams also flow parallel to the range crest.

In a crystalline complex faults must be largely inferred, and many may exist without possible proof. A study of the physiography will frequently do much to elucidate movements in the rocks, but only with great care. In this portion of the Sierra Nevada there are abundant physiographic features that can be used as criteria of faulting, and the whole process is rendered certain by the possibility first of applying exact stratigraphic evidence in deciphering the precise nature of the physiography, and then applying the physiographic tests in the crystalline rocks.

The type-section across the range lies along the line of the old river channel, west of the south end of Washoe Lake. Three main ridge lines and three sub-ridges are developed. The stratigraphic relations are clear. Seven fault-blocks are represented in this section. Of the eight fault-planes bounding these blocks, the existence of but one is not at once proved by the position of the gravels. This is due to the fact that at this point the gravels are scattered over the surface and no section across the fault-plane is to be had. The proof of this fault is adduced through the significance of the topography. A glance at the map on this section shows the crest of a sub-ridge on the east of the fault-plane, forming the apex of the block on that side. Both directly and indirectly this crest of the block can be shown to be due to a fault. First, this fault-line is an extension of the one so clearly defined by displacement of plateau remnants on Snow Valley Peak, and here separating the east and west summit ridges. Secondly, at every place where such sub-ridge crests occur within the area, they can always be proven due to faulting when direct evidence is obtainable. The old plateau surface was character-

ized by no such peculiarities of the topography. Lastly, there is no evidence of stream erosion on any side of this particular sub-crest. These peculiar sub-crests, or the apices of fault-blocks, are so striking and important a feature of the topography that further discussion here is not amiss. A good example is found south of Marlett Peak. The unequivocal fault-plane that bounds Marlett Lake on the east passes north just west of Marlett Peak, faults the river gravels, and extends further to the north for about a mile before its traces become lost. The west wall is dropped relatively to the east. North of Marlett Peak a sub-ridge has been formed, and on this are situated two crests. The southernmost of these two crests is on the old river channel; the northern one is all in granodiorite. The nature of the first is plainly evident from stratigraphic evidence. The other then becomes likewise clear. Each crest is separated from the higher crest to the west by a narrow valley or col, in which are found products of deep rock disintegration. No stream has ever flowed in these cols, and no running streams are near either of these sub-crests. The movement along the fault-plane appears in all cases to have so fractured the bounding walls that rock disintegration has been comparatively rapid and atmospheric erosion correspondingly great. But there is a further characteristic of these sub-crests, viz: their buttress form. The question is instantly forthcoming: If these sub-crests are due to north-south faulting, why is the crest not a ridge line instead of a dome? To answer this, attention must be called to the intense east-west faulting and fracturing. The major faulting has always been along north-south lines, but much induced secondary movement has taken place at right angles. The latest large central movements appear to have been concerned with the north-south tilting of a few large blocks and the elevation of others. These will be discussed in the proper place. Actual dislocation in an east-west direction is proved by hypsometric discordance of plateau remnants, river gravels, and volcanics, the presence of typical fault-scarps, and stratigraphic discordance in the schist areas. While in many cases the buttress form of the sub-crests or lesser fault-blocks can at once be proved to be due to faulting in any one of the above ways, it also is a fact that in all cases with the facts

at hand no other hypothesis seems able to account for this form.

Throughout the whole region north of Clear Creek these buttress-like forms or fault-blocks are found, some of large size, and many small. Some typical ones are worthy of note. Two are shown in plate 23B, one on each side of the creek. They are several hundred yards long and relatively narrow. The top of each is level and covered with loose boulders of disintegration and coarse sand. Each is separated from the higher blocks adjacent by a long, narrow col. These cols are filled with deep sand composed of the angular fragments of disintegrated granite; no trace of stream-worn material is present. The side slopes are sharp-cut and unbroken. The ends of the blocks descend steeply under the deep sand. The creek is far below and distant from the two blocks shown, and no streams have ever been on or near them. We are thus justified in regarding these blocks and buttress-like forms as the products of rock dislocation. Further discussion will be had under the treatment of Little Valley.

From the cross-section of the range through the old river channel we thus obtain conclusive evidence of the faulting movements in north-south planes. To the south the faulting becomes even more complex until the Genoa topographic area is reached. The key to the whole, however, is given by the section described, as the major fault lines are continuous. The greatest complexity of the rock movements is in the schist area east of Snow Valley Peak. As already noted, the long east slope consists of a series of step-like flats connected by steep rises. This schist area is deeply notched by a number of east-west stream gullies. If the north-south plane through one of the steep rises be traced into the gullies on either side, the existence of a north-south fault is stratigraphically shown. This cannot be done in all cases, but wherever the test is possible, a fault-line is shown. Further, the stream courses themselves offer a different and as conclusive a proof. The bottoms of the several stream courses are all step-like in profile. Opposite the flats, the streams are cutting slowly; opposite the steep rises, the waters descend in cascades and rapids and are cutting comparatively very rapidly. The first steep rise west of Kings Cañon is the most pronounced of all and is probably the most recent. This rise is an unequivocal scarp stand-

ing almost vertical in places. The creek that enters Kings Cañon a little over a mile from the mouth does so in a series of three falls, aggregating over sixty feet in height, the largest being over twenty feet. Above the falls the creek, although it has trenched quite deeply, yet flows over a comparatively gentle grade. At the summit of the falls the fault fissure in the schists is strikingly in evidence, and the schists themselves are in discordance with the normal strike and dip. Furthermore, the rock exposed is perfectly fresh, a condition not found elsewhere. Both structurally and physiographically this small fault-scarp is the most recent in this immediate area. The question now comes naturally, why do the other creeks tributary to Kings Cañon not show similar falls at this most recent fault line? This question leads into the next important sub-topic under faulting.

On the creek having the "falls" there is little or no discordance in the schist on either side of the stream near the falls, and hence no considerable east-west cross-faulting. The creek gullies north of this connect with the flow of Kings Cañon by gradual slopes without trace of falls or rapids. But in these side cañons the schist walls on either side are not in accordance and each creek is flowing over the trace of an east-west fault. Ash Cañon, to the north, is likewise a fault cañon, as is evident even from the geological map. Thus the large schist area east of Snow Valley Peak is broken by many north-south and east-west faults. The topography shown by the map expresses this; in the field the topographic evidence is much stronger. The main creeks flow over fault-planes. East-west movement near the falls is not noticed, yet there appears to be some discordance above. And the deep notch cut by the creek in the upper courses indicates a weak zone which must be structural, for it is not due to differential rock hardness. North of Ash Cañon the granitic mass is intensely fractured and faulted. The many small dikes of andesite are badly dislocated. The large dike on Lakeview Hill, which is mapped, shows the same character.

Lastly, under the faulting of this topographic area comes a consideration of the peculiarities of the drainage, with the faults bounding them on north and south. Thus far it is evident that most, if not all, the main creeks flow over lines of weakness due

to faulting and shattering of the rocks. Clear Creek, however, has not yet been mentioned, as it flows entirely over granodiorite. There is a deep cañon for several miles up this stream, which does not carry a great volume of water. These is no indication that the creek ever was sufficiently large to be able to cut such a large cañon. Nor is such a hypothesis necessary when the topography is examined. Were the cañon water-cut, the two sides, being of identically the same rock, and under the same conditions, should be of similar form. This is not so. In the lower courses the north wall is precipitous and high, while the slope of the south wall is comparatively gentle. About three miles above the mouth the north side is an alluvium covered flat, while the south wall rises very steeply for nearly 1,600 feet. Further, the line through Clear Creek if prolonged westward passes through the granite fault-scarps north and southeast of Glenbrook Bay and along the south boundary of the down-dropped block underlying the valley at Spooners. Lastly, this rather prominent structural line marks approximately the south boundary of the intensely faulted Carson topographic area. For all these reasons the course of Clear Creek, with its prolongation westward, is held to be a fault-line; no other hypothesis appears able to account for all the facts.

The next structural feature of importance connected with the drainage is Kings Cañon. From Eagle Valley a view up Kings Cañon shows what appears to be a mature valley topographically not consonant with the other features of the geomorphy. The cañon is flat-bottomed from a distance, and its course is longitudinal rather than transverse. A careful examination, however, reveals the true characteristic of the cañon. The cross-section of the valley is asymetric, the lowest part lying on the east side. The east and west walls rise steeply, and the bottom slopes at a low angle from the west to the east sides. The cañon comes rapidly to an end about three miles above its mouth, at the prominent ridge extending eastward from the mass of Snow Valley Peak. The other side of this ridge falls away in a very steep fault-scarp, on a fault parallel to Clear Creek. The creek in Kings Cañon is small, and practically nothing above the branch carrying the falls. It is trenching the material in the cañon, and there is thus exposed, not rounded stream boulders

and silt, but angular blocks and loose rubble characteristic of the talus cones of torrential streams working at high grade. If these facts be insufficient to prove a structural origin for Kings cañon, there yet remains some stratigraphic evidence. The rocks on both sides of Kings Cañon are of the same metamorphic series. Their character is different on the two sides, however. On the west altered sediments in the form of thinly fissile schists occur, while on the east the meta-andesites are in great evidence. Were the cañon parallel to the strike of the rocks, a single explanation of this fact would at once be suggested. Such is not the case, however, as the average strike approaches closely north-south. A second point is found in the tongue-like small schist area at the head of the cañon. The northwest side of the tongue is about coincident with the road, and the schist is found abutting against the foot of the steep granite rise to the west. As has been shown, the granite-schist contact is roughly a plane dipping gently eastward, and no sunken schist areas of any size are found. Hence this tongue can be attributed only to a fault. Moreover, the line of this contact when prolonged passes through the fault at the head of the falls. This fault line appears to be the major one, lying slightly to the west of the creek line in the upper cañon and crossing into the lowest part of the cañon below the falls.

Thus the three principal eastward flowing creeks in the Carson topographic area flow in fault cañons. There is only one other flowing the same way that here requires notice. This is the first creek north of Ash Cañon, flowing entirely over crystalline rock. There exist a number of facts which tend to prove the course of this stream a fault zone. In the lower course the stream has built a large alluvial fan that separates two areas of schist. Of these two small schist areas the southern reaches a high elevation on the granodiorite, or better, the contact plane between the schist and granodiorite is higher in the southern area. A warping of this contact surface would be able to present the same result, but such warping has not been noted on the large areas where it could be detected if present. More than this, the ridge just north of Ash Cañon has been thrust relatively eastward between parallel east-west faults. Warping above will not account for this. Above the alluvial fan the creek has two branches,

both flowing in deeply notched cañons. Very little water flows in either branch except during stormy weather. The granodiorite appears to be peculiarly nonresistant to stream erosion along the drainage lines and great quantities of coarse granite have been deposited on the alluvial fan below. For the reasons already given, in this area of rocks that possess slight variations in resistance to erosion, such condition is best explained as the result of rock fracturing and weakening along fault planes. And on both branches there are granite walls that can hardly be regarded as other than fault-scarps. Furthermore, there is another bit of evidence to substantiate the idea of faulting. The plateau remnant east of Marlett Lake ends abruptly against a fault-scarp striking nearly east-west. This scarp is proved to be due to a fault by the hypsometric discordance between the two nearby plateau remnants. The prolongation of the line of this scarp leads directly to the line of the south fork of the creek just discussed. There is a well-developed scarp between this line and Ash Cañon, and no stream has ever cut at its base.

More examples of east-west faulting and drainage following these faults could be given, but there is no need. Sufficient facts have been cited to show the great number of east-west cross-faults, with the consequent drainage.

Of the north-south consequent streams there are a number of good examples in the Carson topographic area. The upper part of Franktown Creek is clearly flowing in a longitudinal valley due to faulting, as shown in the section along the old river channel. The small creeks at the southwest corner of Washoe Valley are likewise longitudinal streams. A fine example of such a stream is found just south of Marlett Lake, west of Snow Valley Peak. The faults which have resulted in the down-dropped block under the lake appear to have converged and joined west of Snow Valley Peak, and continued southward along the line of the creek just noted. The origin of the cañon is proved by the existence of this fault line prolonged from the north, in the presence of steep unnotched granite fault-scarps; and the dislocation of the old plateau surface. The upper portion of this cañon is almost U-shaped, very suggestive of glacial action. The complete absence of glacial deposits and scorings, the uniform disintegra-

tion of the surface rock, and the evident impossibility of any great volume of snow occurring here, all render this conception highly improbable. Where the cañon is flaring in cross-section, with wide bottom, the small stream is cutting in talus from the bounding scarps, quite similarly to the creek in Kings Cañon. This material finds its way to the bottom faster than the creek is able to carry it below. But there are other peculiarities to this longitudinal cañon that, most unfortunately, the map fails to show. The cañon is clearly divisible into two very dissimilar parts. The nature of the upper portion has been briefly discussed. The map shows the upper creek as draining southward to Spooner Valley; the fact is that it does no such thing, but at a line of east-west faulting at the schist-granite contact, turns westward and flows through a narrow rock gorge into Lake Tahoe. The idea of stream capture at once suggests itself. The other accessory facts, as far as they have been determined, are as follows. The creek flowing westward, whose headwaters were at some time extended sufficiently to capture the drainage in the north-south cañon, is normally a small wet-weather stream with no drainage basin beyond a few acres in area. The north-south creek at the point of sharp turn to the west, carries considerable water at all seasons, being fed by perpetual springs at the head of the cañon. The small gorge through which this creek leaves the main cañon is sharp-cut and rocky, and apparently not due to stream cutting. Further than this, were the small gorge to the west stream-cut it must have been made by the larger creek, for the small wet-weather stream is unable to do such work. This would presuppose that originally there was no gorge but at most a shallow notch in the ridge at this point. If such a condition obtained, the larger creek would be forced to flow on down the longitudinal cañon. Hence the peculiar turn of the large creek to the west cannot be due to stream capture and must be of structural origin. This hypothesis is born out by other facts. The deep steep-walled cañon through which the creek flows westward possesses what is in this region the most common characteristic, a fault cañon. The stream at fairly high grade is trenching in the granite sand carried down from the steep walls, similarly to Kings Cañon Creek; the rock disintegration is proceeding

faster than the stream erosion. This crumbling of granodiorite appears to be due, as in the other cases cited, to the great fracturing along the fault-planes. However, the presence of the fault is actually demonstrated stratigraphically by the position of the schist area on the granodiorite. The crust block which carries the metamorphic rock has been dropped relatively to the northern area.

Below the point where the creek turns westward and leaves the main north-south cañon, the bottom of the cañon changes abruptly from the wide, flaring portion above. The smooth open curves of the upper cross-section give place to sharp angles and constricted cross-section, and the fine rock debris to large blocks of granite. The creek which flows in the lower cañon is cutting the solid rock at a high gradient. The fault-line in this lower portion is further emphasized by the stratigraphic evidence of the sunken schist block. A question arises concerning the relative ages of the longitudinal and cross-faults at this point, and whether or not it is possible to determine them. We are confronted at once with a seeming discrepancy in the facts—a fault which at once has caused a downthrow of the schist block and dammed the creek, so as to produce an abrupt change in the drainage line. In the explanation of this paradox some idea of relative ages of the faults can be gained. Obviously the large north-south cañon is the oldest physiographic feature that is due to longitudinal faulting movements. Also, the small schist area north of Spooners forms the west wall of the lower portion of this north-south fault cañon and was therefore concerned with the first movements. But it is clearly a drown-dropped block, proved by the comparatively low elevations both of the granite-schist contact plane and of the plateau remnants. It is therefore safe to conclude that the schist block must have been bounded on north and south by east-west cross-faults at the time of the formation of the north-south cañon. This makes *some* east-west faulting of same age as the main longitudinal motion. But, the lower cañon shows evidence of slight elevation of the schist block subsequent to the formation of the first fault features. From this, a later period of east-west faulting, with secondary north-south faulting, is inferred. This conclusion in regard to relative ages of faults is

substantiated by the faulting in Little Valley, described later. Further investigation in the field will undoubtedly throw more light upon this particular question.

Two other creeks flow in longitudinal courses over part of their lengths west of Snow Valley Peak. These both flow over the trace of the same fault-plane, one that is strongly marked in almost unnotched fault-scarps. And small as are these creeks, there is one very important point to be made clear by an examination of their different branches. In the creek west of Marlett Lake there are a number of branches. The central one and the northern carry about the same amount of water. Yet the central one has cut hardly a notch, though flowing at a somewhat higher grade. The northernmost, however, flows in a decided angle in the fault-scarp. There is an east-west fault passing through the north end of Marlett Lake, bounding the down-dropped block. It finds expression in the notch of the northern branch of the creek, which thus takes on a new value. Similar occurrences can be noted elsewhere on the sheet mapped. The south branch of the creek just west of Marlett Lake and the north branch of the creek west of Snow Valley Peak flow over the fault-plane that forms the eastern boundary of the westernmost fault-block in this section. There are thus two lesser faults between Snow Valley Peak and the larger fault forming the east boundary of Lake Tahoe. This step-like feature of the faulting is its most constant characteristic.

The important physiographic criteria of faulting in the area of plutonic rocks can be briefly summarized thus, in order of relative importance: (1) unmistakable fault scarps; (2) step-like character of mountain profile, accompanied by corresponding rapids and gentler courses in the streams; (3) steep-cut rocky buttresses separated from main peak or ridge by distinct cols; (4) sharp jogs in an otherwise smoothly flowing slope, which may or may not be occupied by small creeks. On Prison Hill there are no streams; just west across the valley there is a very small flow in wet weather; in the higher mountains the creeks are frequently quite large; (5) consequent longitudinal streams flowing in distinct valleys, often of considerable size and with a floor of coarse granite sand.

The Franktown Area.—The Franktown topographic area adjoins the complex Carson area on the north. Although it is almost entirely composed of granitic rocks, it furnishes some definite proof of the relative ages of faults, or lines of faults. It contains the most striking physiographic feature of the whole region—Little Valley, a large, well-formed intramontaine longitudinal valley. The Franktown and Carson topographic areas are separated by a fault-line through Incline and the south end of Washoe Lake. South of this line there are three longitudinal ridge lines, as already noted. North, in the Franktown area, there are but two ridge lines, a high western one, that forms the true crest, and a low eastern one, just above Washoe Valley. A few buttress-like crust blocks also are present, as are evident from the topographic map, east of Incline. Besides these larger forms there are many smaller ones, some of which, in the southern part of Little Valley, have received notice. In the north part of Little Valley there are a number of small blocks which are so peculiar that especial notice is deserved.

Climbing westward from Washoe Valley near Franktown, the low east ridge is ascended, over the granite fault-scarp rising out of the valley floor. From this ridge summit one looks east straight down to the valley 1,400 feet below, and west, first down gently to the level floor of Little Valley, then beyond to the massive and imposing granite wall which rises unbroken for over 2,000 feet to the range summit. From the range crest the slopes descend steeply to the west, except in the northern part. Little Valley itself thus lies between two ridge crests, and strikes about north and south. It is clearly a structural feature, following the longitudinal fault of the high scarp to the west. The features of this valley furnish a clue to the explanation of much of the faulting of the region, and will therefore be described in detail. Following this description, a critical examination will be made of the several features, and conclusions drawn regarding their significance. A portion of Little Valley lies within the Carson topographic area, but the valley will here be treated as a physiographic unit.

An east-west cross-section through the central part of Little Valley shows it to occupy the low area between two crust blocks,

one of which has risen relatively to the other. If this section be taken through Franktown, the position of the plateau remnants brings out this structure prominently. The block to the west, which here forms the main range crest, is bounded on both sides by steep, unbroken scarps, hardly notched by stream erosion. To the east of Little Valley, a slope rises to the crest of the fault-block on that side, first gently and then steeply. This east crest descends to Washoe Valley over a gentler slope than the scarp to the west. The lower fault-scarp, however, is not uniform. Near Franktown a portion is very steep; south of Franktown Creek Cañon the slope is comparatively low; further south the steepness again increases. As a physiographic unit, Little Valley has clear and definite boundaries north and south, ending well to the south of Slide Mountain. As a structural feature the valley extends northward east of Slide Mountain at least as far as the limits of the map. The low eastern crest is plainly to be seen on the east flank of Slide Mountain. This is much more impressive in the field than on the map.

Longitudinally, Little Valley is divisible into three sharply distinct parts: northern, middle and southern. The north portion lies north of the forks of Franktown Creek; the middle lies between the forks and the sharp jog in the creek half a mile south; the south part embraces all the valley south of the jog just noted. The reasons for this division are physiographic and structural, as will appear later; that there is also a reason of a different order is evident from the hypsometric discordance of the several plateau remnants associated with the valley boundaries.

The middle portion of Little Valley is the simplest, and will first be described. The valley proper is flat-bottomed, deeply alluviated, and nearly half a mile wide. To the west the valley floor connects with the west fault-scarp by the gentle upward slope of an alluvial apron. Above this the scarp rises as perfect as if cut by a giant mason. To the west the valley floor first rises very gently to the foot of the slightly higher slopes leading up to the summit of the east ridge. On the crest of this ridge is a distinct remnant of the old plateau, which seems to have suffered little or no tilting. The creek is cutting into the valley alluvium, though sometimes meandering at periods of overload or

A. Range west of Washoe Valley.

B. Little Valley, looking south.

flood. It has already cut about five feet, and has exposed stream-deposited sands and fine gravels, always characterized by cross bedding. At the north end of the middle portion of the valley the creek turns abruptly to the east, and leaves the valley through a sharply notched cañon. The rate of its downward cutting in the granite at the entrance to this cañon governs its work in the valley alluvium. The north branch joins the main stream just before it enters its cañon. This branch has cut deeply into the valley alluvium, disclosing the fact that this material abuts sharply against the south face of the small granite fault-block that bounds on the north the middle portion of Little Valley. A few tributaries flow into the main creek off the steep west scarp; none flow off the east ridge, nor have any ever done so. The absolutely flat floor of this portion of the valley is broken only by the emergence above the alluvium of a few low granite knobs, one of which, shown on the geologic map, is covered with andesite. The position and profile of these small areas of granite are significant, as are the features of the slopes bounding Little Valley on the east. South of the point where Franktown Creek turns to enter the cañon, the few small granite areas in the valley floor are low and level topped. The first slope up to the east from the valley shows traces of a terrace-like fringe of low-lying granite of the same flat aspect. Just south of the east course of the creek above the cañon a long finger of granite extends into the valley alluvium. This finger is also level topped. On all these small areas the surface is deeply soiled with boulders of disintegration lying quite thickly about. The similarity of the appearance of all these small bits of weathered crystalline surface to the unmistakable plateau remnants is remarkable. The low granite slope rising to the east from the valley ends more or less abruptly against a steep rise to the ridge crest capped with its plateau remnant. The eastward slope to Washoe Valley from this crest is peculiar in that in several well preserved sections two distinct slopes are present, joining at a distinct angle whose location frequently shows strong granite outcrops. (See pl. 24a). The higher slope is gentle; the lower steep.

The northern portion of Little Valley presents some striking differences in topography from the middle. Of these the most

noteworthy is the valley floor. This, instead of being flat, slopes upward gradually to the north, with a range of elevation of 700 feet in about two miles. Also, the evenness of the floor is broken by many small granite outcrops, between which there is an accumulation of humus, underlaid by coarse granite sand. The creek here is eroding only the latter material; in no case seen is the solid rock being worn. These granite outcrops are never flat-topped, but show a form in cross-section typically wedge shaped with the edge upward. Lengthwise they form low ridges of considerable length compared to their width. These low ridges always run north and south. The north fork of Franktown Creek has been noted as cutting into the alluvium at the south base of one of these ridges. This face where the stream has exposed it is vertical. One prominent ridge has a width and height of forty or fifty feet and a length of about two hundred feet. The actual apex is of course rounded, and covered with the usual coarse sand and boulders. The lower side slopes are covered with boulders likewise, but the sand stratum is thin, and solid rock is present. A similar statement holds true concerning the plateau remnants and the *steeper* slopes below. The former have both boulders of disintegration and deep sand covering; the latter have many boulders resting on solid rock. The gentler slopes have few boulders and deep sand that is *in situ.*

On the ridge crest east of the north portion of Little Valley is a very well preserved plateau remnant. At the north end of the valley this joins the valley floor, but at the south a steep slope separates the two. This latter slope is divisible near the extreme south end of the north valley portion into two distinct parts. From the summit a steep, almost precipitous cliff descends a few hundred feet to a portion of the ridge which slopes in general gently to the valley. This gentle slope is, however, complex, and is composed of a nearly flat, higher lying part, and a much broken lower portion. The whole of this lower slope appears to be the homologue of the low, gently sloping portion of the east crest just south. From the highest point on the ridge north of Franktown Creek Cañon the slopes also descend in well defined steps southward. There is here also a typical lower point or rock buttress at the crest of the steep cañon wall.

The next noteworthy peculiarity of the south part of Little Valley lies in the existence upon the west fault-scarp of a distinct hanging block. This is shown in a number of instances. At first glance there seems to be a number of these blocks, but a more careful examination reveals the fact that the tops of all the separate blocks lie in the same plane, sloping up gently to the north. All have the same profile and the larger blocks have the same dimensions. The tops are level, joining the steep scarp on the west at a sharp angle. The east sides slope down to the valley at a slightly less angle than the western scarp, the bases being covered with granite detritus. The various blocks are separated by stream gullies, and the smaller ones occur where the stream erosion has been greatest. The characteristics are those of a long, narrow fault-block resting upon the lower part of the steep western scarp that has been dissected by the streams flowing across it. It is also to be stated that the line through the tops of the blocks makes a small angle with the line in the valley bottom, so that the northernmost blocks are little above the valley floor, while the southernmost are several hundred feet above it. These blocks end abruptly at a point about opposite the upper entrance to the cañon of the creek, and below a decided change in slope in the main range crest to the west.

The last peculiar characteristic of this portion of the valley here needing description is the eastern fault-scarp. Franktown Creek Cañon strikes northeast and southwest, separating a steep unbroken slope in the northwest from a longer and gentler one in the southeast. The cañon walls are extremely sharp and precipitous, and both rapids and falls occur in the creek itself. The foot of the steeper slope lies about a quarter of a mile to the west of the foot of the slopes south. Further, it will be noted from the map that north of the mouth of the cañon there is a complementary jog to the east in the slopes up from the valley, and that the foot of the slopes north of this jog are in direct prolongation of the foot of the slopes south of the creek. In other words, the portion of the east fault-scarp lying east of the north part of Little Valley has been shifted a quarter of a mile to the west. This shifting is also plainly expressed in the topography in Little Valley.

The southern portion of Little Valley begins at an east-west line through the jog in the creek about a mile and a half south of its cañon. This line is structural, and of great importance, as the map indicates. It is characterized, from west to east, by (1) a sharp jog in the high west fault-scarp, the south side having moved east over a quarter of a mile; (2) a rock buttress of andesite over and intruded into granite just south of the line in Little Valley; (3) the fact that the flat stream terraces marking the old valley floor occur south of the line *above* the level of the floor of the middle valley; (4) distinct change of slope on the ridge crests to the west and east of Little Valley; (5) a jog in the lower east slope leading down to the Washoe Valley comparable in size to that in the west fault-scarp; (6) a distinct discordance in the elevations of the floor of Washoe Valley and its arm at the southwest corner; and (7) the physical prolongation of the line eastward by the line of north facing cliffs that bound Washoe Valley on the south. The topographic characteristics connected with the high west ridge along this line are rather complex. The very prominent shoulder or offset in the scarp above the jog in Franktown Creek is found to culminate in a granite knob or buttress separated from the main crest by a low flat-bottomed col. Here again is the occurrence of the buttress form associated with an unequivocal fault. The east-west scarp which forms the north face of this shoulder dips northward, and from the position of the buttress at its top is probably not far different from the actual fault-plane. This plane curves slightly southward to the west. But this is not the only faulting apparent on the high west ridge along this general line. At a point on the ridge crest a little north of east from Incline, and nearly a mile north of the col above mentioned, a distinct break or low place occurs. Creeks flow below it east and west, in wide, shallow notches. The west creek lies in a sharp break in the continuity of the slope. Just west of this latter creek occurs a well-formed rock buttress jutting out to the west, as shown on the map.

Along this general fault line in Little Valley there are found two important topographic features. First there occurs a large rock buttress extending from the west scarp halfway across the valley. Its east end has forced the creek to that side of the valley.

Behind it to the south is a flat terrace of river silt and gravels, at a considerable elevation, fifty to one hundred feet, above the floor of the valley to the north. (Pl. 23B). The absence of careful topographic work and of surveys by the writer leaves the exact difference in the elevation yet to be determined. The rock buttress, or earth block, is capped with andesite, and the underlying granodiorite shows many small east-west dikes of the same rock. On the east ridge-crest is a prominent scarp facing north, on the line of the low place in the west crest. A little to the south of this is a second and smaller break and rise on the south side, which can be followed eastward down a shoulder and east-west scarp precisely similar to the shoulder above and west of the valley. Eastward from the foot of this lower shoulder and east-west scarp the line crosses a southerly projecting finger of Washoe Valley. As in Little Valley, the valley floor is broken along the line and is elevated on the south side. In the absence of an exact topographic survey, the precise elevation is not now known, but it is between ten and twenty feet, with the low fault-scarp in the soft alluvium and gravels almost entirely degraded. The distance is less than in Little Valley. There occurs a well-defined fault crossing the east ridge just south of the larger fault-line just described. The gully caused by this fault terminates, on the north, the higher portion of the east ridge, and is followed for a distance by the road into Little Valley.

This southern portion of Little Valley is in its turn divisible into two dissimilar portions, each with its own peculiar and significant features. A lower portion lies between the jog in the creek before described and the turn in the creek to the southeast, proceeding toward its head. The second part lies south of this, and contains that part of the creek that flows northwest. The lower or northern portion is the most constricted and gorge-like part of Little Valley, and has the highest average grade. As in all other parts of the valley, however, the creek is cutting in loose material, with no solid rock yet exposed. It is in this part of the valley that the profile of the walls is especially significant. Both east and west slopes show, not smooth curves, but a series of a few huge steps leading down from the summits into the valley. The largest step on the east side of the valley is

made by a granite block somewhat similar in form to the peculiar granite outcrops in north Little Valley, a long narrow block with a flat top twenty-five or thirty feet wide. On the west of this narrow top the slope leads steeply down to the flat below, forming part of Little Valley. To the east there is a shallow col and then a steep rise up to the plateau remnant which forms the ridge crest. On the west side of Little Valley there are two steps, the higher one of large size and the lower just above the creek and smaller. The actual valley bottom is narrow but flat, being but a few hundred feet across.

The upper portion of this division of Little Valley is of a wide, flaring form, in marked contrast to the gorge-like form below. The general effect is that of maturity (see plates 24B and 25A). The valley floor slopes gradually upward to the south and joins by moderately steep slopes with the highest summits. The steep scarp on the east is persistent southerly to the limits of the valley, while on the west the range crest is reached by a fairly gentle grade, broken, however, as noted before, by a number of subcrests which mark fault-lines. Between these two portions of south Little Valley there is a pronounced structural and physiographic change. This change is along another east-west fault-line between Incline and Lakeview, and is characterized by a variety of effects. From the shore of Lake Tahoe southeast of Incline up to the crest of the high west ridge there is a complex of fault-scarps that face in all directions. These are due to the junction of a number of faults, as shown in the map, one of which is the east-west fault line dividing the two parts of south Little Valley. Where this line crosses the west ridge there is a low pass or col, over which the road to Incline is laid. Eastward from the west crest the line lies between the two dissimilar portions of the west wall of Little Valley. The northern one of these is characterized by fault-scarp topography and absence of well-defined streams; the southern shows a long, gentle slope broken by a few rock buttress forms, and has a well-developed drainage, that is in part at least governed by east-west fault planes. On the east of Little Valley the long ridge, presented for nearly three miles, shows little evidence of cross-faults on cursory examination in the field, and none from the topographic

A. Looking southwest across upper Little Valley. River gravels in foreground.

B. River gravels in upper Little Valley.

map. This ridge crest is flat, or nearly so, for a mile near its south end, and descends to the north by a quite uniform slope. The Tertiary river gravels are preserved upon the higher flat portion, as shown in plate 25B. More careful inspection develops the fact that a great number of cross-faults are present in this ridge north of the flat portion, and that these faults have allowed their north wall to drop relative to the south walls. The north edge of the granodiorite bedrock under the gravels shows well such a displacement, a small one of a few feet. East of the east ridge the line of faulting is first shown by a steep and impressive scarp, followed further east by the marked topographic break west of Lakeview. The andesite area along the east-west fault-line lies within the Carson topographic area and contains the three ridge lines of that area. A view looking southward over the gentle slopes west of the southernmost portion of Little Valley is instructive. (See pl. 24B). In spite of the fact that several buttress forms break the evenness of the profile, the whole is strongly suggestive of a remnant of the old erosional surface tilted to the east. This, combined with the propinquity of the well-preserved plateau remnant near Marlett Lake and the general topographic conditions of the region, makes such an interpretation of the surface certain.

The north portion of the Franktown topographic area is deserving of special mention. Little Valley is terminated in this direction as a physiographic feature by the strongly developed east-west fault that bounds Slide Mountain on the south. The great fault-scarp of this mountain rises almost perpendicularly for 2,500 feet. It gives evidence of being the most recent scarp of size in this part of the country. The name is sufficiently indicative of the nature of this evidence. The biggest slide occurred a few decades ago, and deposited many hundred tons of rock in the cañon. The small lake south of the mountain was formed at this time.

Structurally, Slide Mountain is a portion of the high west ridge line, or the true summit of the range. The low east ridge, so well developed in the Little Valley sections, is present on the east flank of Slide Mountain at elevations from 6,500 to 7,600 feet. It is dissected by eastward flowing creeks and presents a

badly broken appearance. As a structural feature, Little Valley lies between these two crests. These two ridge lines, with the valley between, persists north to the limit of the map, where volcanic flows have obscured the structure. West of Slide Mountain is a locality not yet examined. It is also without the limits of the east range of the Sierra, and is therefore not of primal importance to this paper. The northwest corner is glaciated, and moraines are mapped by Mr. Lindgren on the Truckee quadrangle just west of the map limits.

The Genoa Area.—The Genoa topographic area, lying south of the Carson area and west of Carson Valley, is the simplest portion of the region under discussion. As opposed to the two and three ridge lines of the areas to the north, with their complex faulting, the east-west profile shows but one crest. From Carson Valley a few miles north of Genoa the mountain rises over an unbroken and magnificent fault-scarp for nearly 4,500 feet to the summit of Genoa Peak. The summit of the range is here a well-marked though dissected remnant of the older plateau surface, the most conspicuous of all the many isolated areas. (See pl. 26A). From this tableland the slopes lead in general gently down to Lake Tahoe. The details of structure, as far as made out at present, are not many. The fault-scarp above Carson Valley is broken, not longitudinally, as to the northward, but transversely. There are two well-marked east-west scarps north and south of Genoa Peak, situated in such a position that the peak forms the apex of a four-sided pyramid, whose western side and part of the north and south sides are missing. The general effect is as if a wedge with the edge lying in an east-west direction, had been forced a short distance to the east, by a small motion of rotation about an axis perpendicular to the edge of the wedge. The topographic map shows the lowest contours near the valley are not displaced, but merely notched at the bases of the east-west scarps. But, as greater elevation is gained the main eastward-facing scarp becomes more and more displaced toward the east. Genoa Peak is therefore to the east of the actual crest line. The sharply notched cañons that follow these cross fault-lines are occupied by small wet-weather streams. The question naturally arises, how much of the cañon is due to

A. Genoa Plateau, looking south from Snow Valley Peak.

B. River terrace near Carson.

stream erosion and how much to the intersection of faults? Aside from the fact that the streams are small and incapable of carrying much load, the complete absence of alluvial fans at the points where the creeks debouch upon the valley floor, indicates that the stream erosion and deposition is a negligible factor. This condition is precisely similar to that of Clear Creek. There is a third well-marked cross fault-scarp just south of Genoa, of which the upper part only is shown on the map. A similar partial relative rotation of fault blocks appear to have occurred.

The summit plateau remnant is broken by a number of faults, both longitudinal and transverse. Genoa Peak is separated from the crest line on both north and south by the cross-fault already noted, and the other faults are to be seen on the map.

On the slopes westward from the summit the largest feature that breaks the uniformity is a well-developed sub-crest composed of a fault block west of Genoa Peak. This is exactly similar to those west of Snow Valley Peak, and is well delineated on the map. A well defined east-west cross-fault lies about a mile south of Glenbrook. The long gentle slope east of Zephyr Cave appears to be broken by both longitudinal and transverse faults, but not sufficient field study has been made here to warrant detailed statements.

Summation of Topography.—The east ridge of the Sierra Nevada is thus divided into three distinct topographic areas. The northern or Franktown area is characterized by two ridge lines, a higher and a lower, separated by a structural longitudinal valley. This longitudinal valley is divided into three topographic parts, the southern one being subdivided into two portions. Each of these divisions has its distinctive characteristics, due to the various effects of differential movements in the rocks. The most striking features are the many large and small fault blocks and the hanging block in south Little Valley. The middle or Carson area is characterized by three ridge lines, the center one forming the range crest. Faulting is very complex, so that the east-west profile shows a series of steps leading down from the summit both to east and west. The long east slope is noted for a great number of such step-faults. The main creeks flow in both longitudinal and transverse valleys, of structural origin, and are

therefore consequent. Marlett Lake, with the down-dropped block, is present in this area. The south area is characterized by one ridge line, forming the crest, a magnificent fault-scarp on the east, and a comparatively gentle slope on the west. Genoa Peak, the highest point, lies on the east-west edge of a wedge of granodiorite that has been rotated about a north-south axis in such way that the high edge has moved eastward relative to the base. Other transverse and longitudinal faults occur also. One small sub-crest is found on the west slope overlooking Lake Tahoe.

IV. The Valley Zone.

The Nevada valleys lying at the east base of the Sierra Nevada present some physiographic and structural features of importance to the geomorphogeny of the region. The three valleys, Washoe, Eagle, and Carson, are structurally one, and were the east front of the Carson topographic area forced back to the line of the areas north and south there would be but one continuous valley from Washoe to Genoa. Near the former place andesite flows mask the granodiorite outlines. The instructive features in Washoe Valley are connected with the lake. This body of water lies on the east side of the valley, at the foot of the hills of the Virginia Range. The present lake basin is continuous to the north end of the valley, where a discharge occurs at periods of high water. A low divide is present between Washoe Lake as mapped and the small body of water at Washoe station. This feature is significant, as will be shown later. From the smaller lake a creek flows northward through a sharp-cut though shallow cañon in volcanic agglomerate and eventually reaches the Truckee River. Directly west of Washoe Lake and south of Franktown several streams have cut trenches over ten feet in depth in the valley at the foot of the Sierra, and have exposed a series of lake beds. The same beds are exposed along the railroad track at Washoe and south for about a mile. The beds south of Franktown dip slightly to the east; those at Washoe dip southeasterly at a few degrees. From Franktown south there is also a well-preserved lake cliff cut in the above mentioned sediments. This cliff follows approximately the line of the railroad a short distance east of it. North of Franktown its presence is not yet

certain, though careful examination may reveal its presence to Washoe. The maximum height of the cliff west of the lake is about ten feet, and grows gradually less to the north. It is of very recent formation, for erosion has not yet modified its profile. On the east side of the lake the valley floor slopes very gently in an unbroken line up to the foot of the hills, with no suggestion of a cliff or stream trenching. On the south shore of the lake the waters lap the solid rock, and comparatively deep water exists a few feet off shore. The two stream courses at the south end of the lake are also indicative of differential elevation. The one near Lakeview flows on a due north course to the important east-west fault line already described, at which it turns sharply northeast, flowing thence to the lake. The creek at the southeast corner of the lake, on the other hand, flows by the shortest line to the lake, over a slope covered for the most part with angular rock fragments from the hills. If the abrupt change in the direction of flow of the first creek were due simply to a shrinkage of lake surface, the second creek in its lower part would flow over old lake beaches and deposits. This condition is not fulfilled; the only beach on the east shore is the one now occupied by the lake at periods of high water. The absence of a more detailed topographic map makes exact statements depending upon relative elevations impossible. The 5,100-feet contour is suggestive of a tilting to the east, and taken in conjunction with the presence of lake beds at that elevation on the west and not on the east, is of some value to the present inquiry. The warping of the basin, with the formation of a low divide west of Slide Mountain and the rock shore of the lake at the south is probably due to the faulting that produced Slide Mountain. The best supplementary proof of these movements in Washoe Valley are found to the south.

The course of Carson River from Genoa northward presents some anomalies. In Carson Valley it flows on the west side over a deeply alluviated floor. East of Genoa Peak it turns eastward, follows the east side of the narrowing valley and turns into the rocky gorge south and east of Prison Hill. Thence it flows northward to Empire, where it turns at a right angle and proceeds eastward through the Como Range. In such a region of great

and numerous earth movements, a cause is not hard to find *a priori.* But some exact evidence exists that shows an eastward tilting of the region, with a differential elevation of certain crust blocks. From the point that juts eastward just south of Carson, to Empire, a well-cut stream cliff extends almost interruptedly. It is best preserved on the south limits of Carson (see pl. 26B). The turn eastward occurs within the town, and there are yet found several low cliffs and terraces, as if the river had varied its course on the big turn to the east. A short distance south of Carson, on the toe of the eastward trenching ridge, a typical river deposit has been cut at an elevation of 4,900 feet (see pl. 27A). South of here the alluvium of the valley has masked all traces of the stream. West of Prison Hill is a low divide separating Eagle and Carson valleys, quite similar in nature and origin to the low divide in Washoe Valley. The valley west of Prison Hill is the narrowest portion of the valley south of Lakeview. It lies between two prominent fault-blocks, the recent movements of which are surely the cause of formation of the low divide. Evidence of elevation is present on both blocks, and is best shown on the eastern one. From a little distance Prison Hill exhibits a white band or apron on the lower western slope, that is in striking contrast to the dark metamorphic rocks above. This white deposit slopes up from the valley level at the Prison to a point west of the summit. The material is granitic sand, of either fluviatile or lacustrine origin. On the west side of the valley an exactly similar feature is not found, but the same sort of material is found to nearly the same elevation. The recent alluvial apron along these hills has smoothed all irregularities and covered all masked features. South of Clear Creek, however, the river or lake deposits are much in evidence, and show some terrace-like effects. There are three terraces gravel-covered, and quite prominent in the field, but not sufficient work has yet been done to warrant a full statement regarding their genesis. The lower two are probably due to stream erosion, and the upper, because of its connection with the fault-block south of Clear Creek, is probably due to faulting. That there was some terracing by the older Carson River is shown by the effects in Carson. The highest terrace, northwest of Cradlebaugh Bridge, were it

A. Detail of river deposit near Carson.

B. East-west scarp. Central Little Valley.

not due to faulting, would show elsewhere, which is not the case. The form of this terrace is very interesting, as outlined by the 5,000-feet contour. The embayment west of the gravel terrace might be the result of stream erosion, but no streams other than wet-weather ones flow there. Furthermore, the valley here contains a good soil, with no gravel. At the fork in the road just west of the summit of the terrace there is a distinct alluvial fan whose apex lies above the slope leading down to the lower valley to the west, and thus seems to be a beheaded fan. The faults in the granite south of Clear Creek are evident, and their projection into the valley coincides with the lines of the probable faulting that produced the embayment west of the highest gravel terrace. The projection of the fault-line that runs south from Carson lies in the proper position to have formed the east side of the same terrace. Hence for the present this hypothesis as to the mode of formation of the terrace will be adopted. The formation of the low divide south of Carson is due, then, to the uplift of the bounding fault-blocks, which are here quite near. South of the divide the valley is too wide to admit of equal elevation of the whole valley floor, or the river would have been dammed and a temporary lake formed. The crust blocks on both sides were elevated, however, as already described on the west, and as shown by an elevated line of sands similar to those on Prison Hill, on the hill just south.

From Clear Creek north to Washoe it is evident that a tilting of the valley floor has taken place quite recently, and may even yet be in progress.

North of Washoe a line of narrow valleys forms a connection to the Truckee Meadows, through which the Truckee River flows eastward. From Reno westward a number of terraces of this river occur. The highest slope upward to the west at an angle greater than that of the river, while the lowest has the grade of the river. Careful surveys can here establish the exact amount of this eastward tilting.

IMPORTANT FEATURES OF THE NEVADA RANGES.

There are a few characteristics of the ranges in Nevada that call for description here, because of their close relationship to the structural features already described. In the east part of

the map are shown the west slopes and foothills of a north-south mountain range, divided about midway by the Carson River. To that portion north of the river the name Virginia Range is given, including the Washoe Mountains, as delineated on the map. South of the river is the Pine Nut Range, east of Carson, sometimes called the Como Mountains. As noted on a previous page, these two ranges, structurally one, are a spur of the greater Sierra Nevada. The greater part of their areas is covered with Tertiary lavas, but along their western parts they exhibit structural, physiographic and tectonic features that prove their kinship to the Sierra Nevada. At the north the volcanics extend across from the Virginia Range to the Sierra Nevada, but a mile south of Washoe the granodiorite appears beneath the later rocks. From this latter part to the south limit of the map a fringe of the old metamorphics and intruded plutonic appears along the Nevada ranges on their west side. Throughout this portion of the ranges most of the main faults are apparent from an inspection of the map, as for instance, at Lakeview, Prison Hill, and in the Washoe Mountains north of Carson. A good example of a longitudinal fault parallel to the one just east of Washoe Slope occurs in the granodiorite area east of the lake. A prominent north-south ridge has been formed, that in a well-watered region would have been occupied by a longitudinal stream as in the Sierra Nevada. Fault scarps are common and are best developed in the Washoe Mountains. The steep scarp in the rhyolite area east of Washoe Lake bears every evidence of being an original scarp in the granodiorite and schist covered over by a thin flow of the rhyolite. This is on the line of faulting to the south, near Eagle Valley, and probably represents an extensive line of displacement. The Hot Springs north of Carson are on a line of movement, as is shown by their being easily affected by earthquakes. The fault across Prison Hill is apparently a normal one, with downthrow of the north metamorphic area. This fault is well expressed in the topography. The normal relation of the schist and plutonic is shown by the small schist area on Carson River east of the hill-crest, that rests upon the granodiorite.

In the vicinity of Lakeview the Sierra Nevada and Virginia

Range actually meet and their union is made perfectly evident. On Lakeview Hill the contact plane of granodiorite and schist dips south, entirely different from the adjacent area, on the block just west, that dips east. The contact plane north of Carson likewise dips southerly. Lakeview Hill, therefore, is structurally a part of the Washoe Mountains, and not of the Sierra Nevada. The latter range is bounded strictly on the east by a line of north-south faulting only. A further bond of union is established between the ranges by the presence upon the hills north of Carson of horizontal remains of the old erosional surface. A view southwest from the town shows the hills east of Lakeview as flat-topped as if smoothed by a giant plane. The presence of the Tertiary gravels in these hills is evidence of the same order. Small areas of schist are found in the Pine Nut Range east of the map limits. Granite occurs southeast of Mt. Davidson, in the Virginia Range. It is evident that the older rocks form the basement upon which rest the vast thickness of lavas that make up the main mass of the Nevada ranges. This basement must be broken and displaced in a complex manner, as proven by the varying elevations at which the several areas of older rocks are found.

From the field investigations of the writer, the diorite of Mt. Davidson is of indefinite relationship to the older and later rocks. If the Davidson plateau be the correlative of the plateau in the Sierra Nevada, that antedates the period of vulcanism there, and if the various volcanics of the two ranges be of similar ages, we may need to reopen the Comstock question of ages and identities of the various eruptive rocks upon this new basis, for a final settlement. However, from the various outcrops of those rocks that belong unquestionably to the Basement Complex, it would appear that in general the upper limits of these rocks slope gently downward to the east.

Just beyond the Pine Nut Range to the east lies Smith Valley, and this is bounded on the east by another north-south range, the Sing-ats-e. Here the volcanic rocks are again in relatively small amount, with corresponding large development of old sedimentaries intruded by granitic rocks.[8] The structure of the

[8] Cf. D. T. Smith, Univ. Calif. Publ., Bull. Dept. Geol., vol. 4, no. 1.

Sing-ats-e Range is that of an anticlinal fold, with granitic axis and sedimentaries, largely limestone, resting on the flanks. Metamorphism of the calcareous rocks is extreme, and has resulted in the formation of the well-known copper deposits of the Yerington district. These copper ores are entirely similar in character and origin to those near Carson and Genoa. The pre-Tertiary rocks are therefore at a lower elevation in the Pine Nut and Virginia ranges than further east in at least the one range noted. This condition may be due to three causes, in part to original, hypsometric differences, in part to relative elevation of the Sierra Nevada and Sing-ats-e with the associated Nevada ranges, and in part to the depression due to the great weight of the Tertiary lavas in the Virginia and Pine Nut ranges. All this is of importance to the present paper in helping to establish a close connection between the Sierra Nevada and the first ranges to the east.

The roof of the granitic batholith is very probably not far distant from the upper limit of the pre-volcanic rocks. The question of its exact position and history is one of the many interesting problems yet to be solved. The question of origin of the hot water of the Comstock mines is of interest in this connection. Becker has assumed that the older schists outcropping in the Sierra Nevada to the west were the water-carrying strata. But the schist occurs mainly in isolated areas or thin remnants not carrying water where exposed. Moreover, the contact of schist and intrusive plutonic is distinctly water-bearing near Carson, and not the schists themselves. These facts, taken with the further one of a broad synclinal axis beneath the Virginia and Pine Nut ranges, rather point to the roof of the batholith as the source of the Comstock water. This is compatible with either view of the age of the diorite of Mt. Davidson, if it be assumed that, if the diorite be of pre-Tertiary age, it is also younger than the granodiorite or granite. The presence of a small spot of porphyritic granitic rock has already been noted in this connection.

If, then, the Virginia and Pine Nut ranges be of such close relationship to the Sierra Nevada, and separated from it by flat-bottomed valleys and distinct fault planes, it follows that Washoe, Eagle, and Carson valleys lie upon the summits of

down-dropped crust blocks, or *graben.* This mode of origin, which can hardly be questioned, is rendered the more certain by the presence of prominent fault blocks within the valley limits, quite similar to the blocks present in the floor of north Little Valley. Also, the real similarity of Washoe Lake and valley to that of Marlett Lake, whose origin is so evident, has a bearing on the inquiry. Were Washoe Lake to fill its valley, as it did originally, the three bodies of water, Tahoe, Washoe, and Marlett, would differ only in size.

Lastly, literally as a connecting link, is the presence of the Washoe Mountains opposite the much faulted Carson topographic area of the Sierra Nevada, traversed by the same main east-west fault lines and composed of the same rocks.

RELATIVE AGES OF THE FAULTS.

In the region of intensely complex faulting, which has existed from late Tertiary time to the present, it is impossible from the work already accomplished to do more than outline the history of the orogenic movements. Yet it is possible to establish some order of succession among these various faulting movements that have produced the great Sierra fault zone. The physiographic features in and connected with Little Valley are those that furnish the necessary criteria for this determination. Four distinct times or periods of faulting, with principal movements in a definite direction, stand out pre-eminently, and secondary or induced faulting becomes apparent upon further investigation.

Of all the lines of faults, the north-south is the most important, as this determines the main structural lines of the ranges. In only one place is it possible to demonstrate that at least two distinct periods of this motion have occurred. This is in the section across middle Little Valley. As already noted, the east and west fault-scarps here are greatly different in character and appearance. These differences are briefly as follows: (1) The west scarp rises steeply, hardly notched by stream erosion and but little degraded. The east scarp rises more gently, is dissected by the streams, and is considerably degraded. (2) The profile of the stream courses on the west scarp is indicative of ex-

treme youth; on the east scarp the character of this profile betokens a more mature erosion. (3) The valley line of the west scarp is almost a straight line; no valley lobes have been formed. The east scarp presents a very wavy line at its meeting the valley, due to the formation of a number of valley lobes. (4) Upon the west scarp are youthful characteristics of a different order. In north Little Valley there occurs the hanging block already noted. This block depends directly upon the east-west faulting noted later, but indirectly it bears upon the age of the high west scarp. The physiographic aspects of the scarp above and below the level top of the small hanging block are not different, and since the faulting which produced the hanging block is more recent than the two longitudinal scarps under discussion (to be shown later), the youth of the whole of the high west scarp is established. Further, that part of the west scarp south of the hanging block just mentioned shows another feature of importance. This is the sliding of the broken and loose rock material upon the steep slope, whose angle was greater than the angle of rest of the incoherent rock. There is a further peculiarity in that Little Valley has been produced in miniature at one place. None of these features exist upon the east scarp, as the last vestiges of any such, if they ever existed there, have long ago been removed.

More in detail, the profiles of the two groups of streams upon the west and east scarps are thus delineated in figures 1 and 2. It is to be noted that the west streams have not yet cut downward into the scarp, while the eastern ones have cut distinct gullies or small cañons, and developed the three distinct portions of a stream that has partly lost the characteristics of extreme youth.

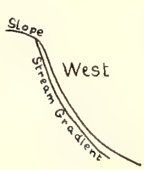


Fig. 1.

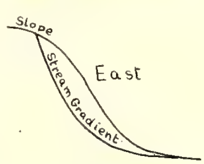


Fig. 2.

The statement that the west scarp is but little degraded, while the east one is much so, needs amplification. The process of erosion of fault-scarps needs investigation, in order to establish definitely the characteristics of a degraded fault-scarp. The ideal conditions necessary to assume in this inquiry are actu-

ally found in the area under consideration. These are (1) an original nearly or quite flat surface; (2) a homogeneous rock with no disturbing features such as columnar structure, etc.; (3) the absence of excessive precipitation of moisture with resultant great stream erosion. In the Little Valley area faults displacing the old plateau surface cut across the massive and homogeneous granodiorite. The erosion of the steep steps due to stream action is small compared to that of the atmospheric agencies, so that the scarps are not degraded in the same manner as slopes in a very moist climate. If there then be assumed a fault dipping at a steep angle, figure 3 represents the original profile.

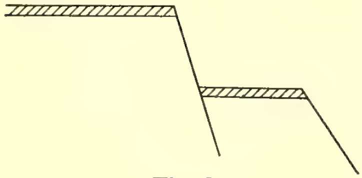


Fig. 3.

We will assume the simplest condition of entirely fresh rock below the broken flat surface. Upon the formation of this scarp the atmospheric agencies will slowly disintegrate the newly exposed surface, the material from which will roll or drop down the steep cliff and form an apron with gentler slope at the base. In the homogeneous rock we have assumed, the disintegration for a considerable time will be quite even over the scarp face and reduce it all equally. The profile then will be as in figure 4.

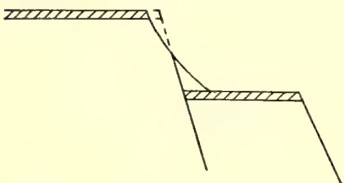


Fig. 4.

There are two segments to this curve. But, while the disintegration is progressing on the face from the outside only, the crest of the scarp is being attacked by the atmosphere both on the side and above. This results in greater disintegration at the crest and a gradual rounding of the salient angle by a rolling of the material below. The third stage in the evolution of the profile is therefore as in figure 5. Here there are three distinct segments: top convex, center on the original plane of the fault, and bottom concave. As the top becomes more rounded and reduced and the lowest slope aggraded by

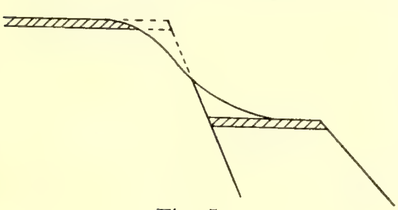


Fig. 5.

accumulated material, the central portion gradually disappears, worn away above and buried below. When this stage is reached the profile is that of a hillside no different from any ordinary one determined by erosion, with two segments, the upper convex and the lower concave, as in figure 6. The stream courses that traverse a fault-scarp under the assumed conditions follow the usual law of erosion. If a scarp show decomposed rock instead of fresh, slides will occur that may modify somewhat the profiles shown, but the results with only moderate alteration of the wall can not differ essentially from those shown. At Slide Mountain, for instance, where the scarp is in the first stage of degradation, the great slides that have occurred have served only to bring out more clearly the profile of a young scarp as given in figure 3.

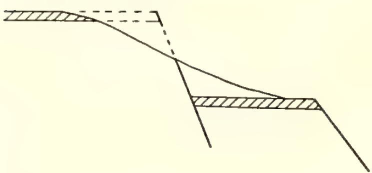


Fig. 6.

In the region west of Washoe Lake all the various profiles can be found well developed. The oldest stages are most clearly shown on the scarp east of Little Valley. Here the profile of three distinct segments is present, and indicates a greater age than the west scarp. The actual profiles are given in figures 7 and 8 for comparison.

Fig. 7.

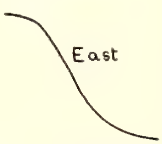


Fig. 8.

A glance at the map is sufficient to convey the fact of greater dissection of the east scarp by streams, and formation of small valley lobes. This is all the better evidence of relative ages, because of the smaller streams flowing on the east scarp. A pertinent question here is one concerning the origin of all the stream gullies on the east scarp. Transverse faulting may be a factor, and probably is to some extent. But this being so, the greater age of this scarp is the more clearly presented.

The bearing of the hanging block has been sufficiently discussed.

From the above facts and principles, it is concluded that the two fault-scarps associated with Little Valley are of different ages and therefore represent two periods of north-south faulting.

The older uplift formed the east scarp, and at the time the various surrounding plateau areas were all probably one. The second uplift raised the high west ridge and range crest and formed the structural features underlying Little Valley. The fault through Little Valley is the most important north-south fault east of Lake Tahoe and north of the Genoa topographic area, judging by the physiographic features of the country traversed.

The next important faulting in order of relative age is that in an east-west direction. As noted before, the presence of north-facing scarps that have caused distinct jogs in the walls of the north-south scarps, the faulted creek gravels in Little Valley and to the east, and the jogs in Franktown Creek and the stream in south Washoe Valley, all indicate a movement along an east-west plane later than the two longitudinal faults. A little consideration makes it evident that this east-west motion is of at least two periods. Both in Little Valley and in the valley next east of its south part the prominent east-west scarps and the dislocation of the creek deposits are the results of faulting of two different orders. In Little Valley, were the cross-scarp and faulting of the gravels contemporaneous, there must have been a compression of the creek deposit south of the cross-fault, with resultant deformation by the great narrowing of the valley. From the stream terrace in this part of Little Valley, such deformation did not occur; in other words, the gravels composing the faulted terrace appear to have been deposited after the narrowing of the valley. This establishes at least two ages of the east-west movements. Supplementary evidence is not lacking. In the small fault-block south of the jog in Franktown Creek, on the line of the east-west scarp, a complex of east-west fractures is filled with small andesite dikes, that were intruded at the time of this motion. Likewise on the line on the floor of Little Valley and in the east ridge occur other small patches of the same rock. Fragments of this fine-grained and somewhat porous andesite are found, showing strongly grooved surfaces, representing a movement later than the time of the intrusion. These grooved fragments show no slickensides, the rock appearing unable to take a polish. This characteristic seems to be due both to the inherent porosity and to some slight alteration previous to the initiation of further faulting.

Evidence of like import is found associated with the growth of Slide Mountain. The main fault underlying Little Valley extends northward to the limits of the map, but has been displaced to the east on the east flank of Slide Mountain. The east ridge here has been badly broken and much displaced, yet is plainly present. The main outline of Washoe Valley must have been established at this time, for the preceding characteristics must surely have been effected by such a great movement, and there exist no traces of later movements sufficiently large to have been able to form so important an element of the physiography.

The last and slight motion along the east-west fault-planes already discussed has probably caused the warping in Washoe Valley, and the low divide east of Slide Mountain, by movements along the same line and resultant compression of the alluvium of the valley. The contemporary movement along the east-west fault bounding Washoe Valley on the south is probably responsible in part for the tilting of the valley to the eastward. Later movements up to the present, the resultant of a complex series of faults, have continued the tilting of Washoe Valley, as well as Eagle and Carson valleys. This establishes four distinct periods of faulting, not counting the later and lesser movements that have produced and are almost certainly still producing slight physiographic change. But these do not cover all the important and visible effects due to movements within the rocks. In the Franktown topographic area there are two groups of such movements not yet placed in time. One of these groups is connected with the structure and genesis of Little Valley, and will be discussed under that head; the other group is concerned with the boundaries of Washoe Valley.

Washoe Valley is roughly rectangular, and the southwest corner is sharply a right angle; the southeast corner is more rounded, due in part to rhyolite flows. The main valley projects in a triangular shaped area south to Lakeview, separating the Washoe Mountains of the Virginia Range from the Sierra Nevada. The south boundary of the main valley is therefore a rampart of hills broken near the middle. The two portions of this rampart are hypsometrically discordant, the western group standing roughly 500 feet higher, using the plateau remnant as a datum plane.

Further, the fault-line or lines bounding Washoe Valley on the east extend southerly through the Washoe Mountains into Eagle Valley. East of these lines the old plateau surface is again at a higher elevation, at least 6,000 feet. The north faces of both portions of the south boundary of Washoe Valley are on the same line of motion, and the fault limiting the Washoe Mountains on the south is the same that extends westerly into the Sierra Nevada. The low portion of the Washoe Mountains, standing between Washoe and Eagle valleys, and forming a connection between the Sierra Nevada and Virginia Range, appears to be a faulted block that remained above the level of the adjoining ones north and south. It is connected with the nearby hills of the Sierra Nevada not only visibly, but also by its general structural and physiographic features. These are in the main evident from the maps. Also, the closer relation of Lakeview Hill to the Washoe Mountains than to the Sierra has been noted. But there is one bond of continuity not yet discussed. The hills embraced within the two-mile square southwest of Lakeview is physiographically as well as structurally a prolongation of the Washoe Mountains, and as such is quite distinct from the rest of the Sierra hills adjacent. This square area southwest of Lakeview is also a part of the badly faulted Carson topographic area and contains the eastern section of the Tertiary River. All these facts are reviewed at length to throw possible light upon the age of the east-west faults south of Washoe Valley, and the formation of the Carson topographic area.

From the facts already cited descriptive of the effects of the second and lesser period of east-west faulting, it is obvious that the southward facing hills bounding Washoe Valley on the south are older than this last marked time of orogenic movements. Nor is it probably of the same age as the first period of east-west faulting. At this time the motion south of the main east-west line through the south end of Washoe Lake was one of elevation and eastward movement. This will be discussed more fully a little later. This movement toward the east would produce compression in that direction, assuming, as there is no reason for not doing, that the Virginia Range was not moving simultaneously and independently. But a triangular dropped block or *graben*

exists between the two sections of the hills bounding Washoe Valley on the south, that could not have sunk under a condition of compression. Also, the condition of the west end of the Washoe Mountains indicates, not a compression, but a relative tension, allowing the block there to sink a few hundred feet below the adjoining ones east and southwest. The several movements coincident with the first, or larger, east-west faulting, seem to have elevated, relatively to the Washoe Mountains, the two-mile square northwest of Lakeview, and to have produced a similar and greater elevation of the high summits to the south and west. This upward movement in the square area is a second factor causing compression along the east-west line of section. On the other hand, since the formation of the diastrophic valleys of Washoe, Eagle and Carson rests upon a tensile stress in an east-west direction, and since the structure along the east-west line through the Washoe Mountains is indicative also of tension, it is believed that the connection between the Virginia Range and the Sierra Nevada was established contemporaneously with the formation of the present valleys. This would make the age of the east-west faulting south of Washoe Valley contemporaneous with one of the periods of the north-south motion, and thus earlier than the two ages of east-west movements already discussed. The direct actual evidence now in hand can carry us back no further. The larger movements that have resulted in the grander physiographic features are to be grasped only by an extended survey over the larger region surrounding Lake Tahoe and the Virginia Range. Yet there are a few general facts of structure and physiography that will serve to establish a working hypothesis to guide future investigation. These facts center about the badly faulted Carson topographic area, and are briefly as follows:

(1) The same general line of movement bounds Lake Tahoe and the Carson topographic area on the north, and the Virginia Range on the south. The Carson River follows this structural break between the Virginia and Pine Nut ranges in its course to Carson Sink. (2) The north-south line bounding the Virginia Range on the west lies west of the line similarly bounding the Pine Nut Range, or in other words, the Virginia Range has suffered a relative displacement to the west. (3) The character-

istics of the Lakeview connection of the Washoe Mountains and the Sierra Nevada indicate that a relative compression at that point has held up the crust-blocks forming the connection, while allowing the more widely spread tensional stress to form the diastrophic valleys on north and south. Taken in conjunction with the directions of the main fault-lines, this would indicate that the Virginia Range block overlapped the area composed of the blocks within the Carson topographic area in such a manner that a maximum compressive force was developed at the contact. This condition would occur if the south end of the Virginia Range were rotated clockwise, here westerly, about a vertical axis somewhere to the north. This is not in discordance with the known characteristics of the region influenced by such motion.

(4) The north end of the Pine Nut Range seems also to have been influenced by a force tending to move it in a westerly direction. This apparent force may have been, and probably was, the resultant of the forces producing mere elevation. An impressive fault-scarp bounds the Pine Nut Range on the north. The final resultant of the two sets of forces from the Virginia and Pine Nut ranges was to set up within the Carson topographic area a complex of stresses and strains in addition to those it already possessed as part of the Sierra Nevada. The many north-south and east-west faults were probably thus established. If the two main compressive stresses at Lakeview and south of Carson were equal or nearly so, these, together with the north-south forces of uplift in the Sierra, would produce a rectangular system of faults. If unequal, differential motion would occur along shear planes not coincident with either of the rectangular lines. The character of Kings Cañon and its fault has been noted. The direction is approximately 45° with the rectangular faults. The upper part of the Ash Cañon fault is likewise aligned. The faults bounding the Lakeview Hill block also make angles of about 45° with the main fault-line. Another prominent southwest-northeast fault occurs three miles west of Lakeview. These diagonal fault-lines are in all probability the result of the shearing stress set up by a force acting westward at Lakeview. The projection into the valley of the lobe southwest of Carson is almost certainly due to an elevation of the Prison Hill block, caused in its turn by a prob-

ably upward movement in the Pine Nut Range. Had the latter block alone been raised, the valley floor would have suffered some tilting to the west. Such tilting has not been recognized directly, though careful surveys may show it. On the other hand, the old channel of the Carson River may indicate that the river was forced to the west side by an elevation of Prison Hill. Further, the very evident fault-line on Prison Hill prolonged westward across the valley joins another evident fault north of Clear Creek, along which the north side has moved relatively eastward. This would require merely a greater elevation of the east than the west side, and not necessarily an absence of elevation on the west. From what facts are now known there appear to have been two uplifts of Prison Hill and the block east of Kings Cañon. The first caused in part the projection eastward of the hills southwest of Carson, between Kings and Clear Creek cañons, and moved the Prison Hill block as a unit. The second caused the further eastward projection of the hills south of Carson to within a mile of Clear Creek, and the slight projection westward of the south half of Prison Hill. This latter movement dammed the old channel of the Carson River and turned it to the east, as already noted. The complete history of the Carson River is a very fascinating problem yet to be solved.

All these many facts centering about the Carson topographic area form a basis for the belief that the important east-west fault line was established very early in the history of the orogenic movements of the region, probably at about the time of the first north-south faulting that can be discerned. For the effects of the east-west movements exist near Lakeview associated with the lower and older north-south scarp, while the upper scarp is broken only by the distinctly later east-west motion. Further, the faulting west of Lake Tahoe has been recognized by Lindgren as entirely pre-andesitic. The scarps on the east side of Lake Tahoe are later than the rhyolite and some andesite flows. It is not impossible, then, that the eastern north-south faulting was contemporary with the main faulting to the west, and that the later movements, entirely confined to the east slope of the Sierra, were begun with the second period of the north-south faulting best represented by the scarps on the ridge crest between

Little Valley and Lake Tahoe. This would mean that the Tahoe Moat was blocked out in early times, and reached its final form at a later period. In the light of our present incomplete knowledge, more discussion would be out of place.

STRUCTURE AND GENESIS OF LITTLE VALLEY.

The four periods of faulting, with the principal direction of each, have been noted for the Little Valley area. These faults are along rectangular lines, north-south and east-west. A very casual glance at the topographic map reveals two prominent north-east and south-west fault lines that call for explanation and a determination of their proper position in time. To this end the complete structure and genesis of Little Valley must be discussed. To summarize what has been already stated, the first north-south faulting formed the lower scarp rising on the west side of Washoe Valley, and probably formed but one crest in this east ridge of the Sierra Nevada. The second period of faulting in the same direction formed the west scarp, the high west ridge, the present boundaries of Lake Tahoe and of Lakeview, and established the important north-south fault-line upon which Little Valley was formed. The next period of faulting was in an east-west direction, and displaced the Little Valley fault-line by the elevation of Slide Mountain. Also the floor of Little Valley was faulted at the distinct jog in the creek and at other important places not yet discussed. The last east-west faulting was small and did not change the valley characteristics. This summary leaves much unexplained and leaves out of consideration some of the essential features connected with Little Valley.

From what has already been noted regarding Little Valley it is evident that the present form and complete structure are posterior to the last period of north-south faulting; the earlier east-west faulting movements have considerably modified the valley. Upon analysis of the dynamics of the faulting it appears that this east-west movement is responsible for the main structural features.

The lower east ridge is already divisible into four blocks, each of which is broken by a number of lesser faults. The first block occupies the area between the Slide Mountain fault and the

northeast cañon of Franktown Creek. The second lies between this cañon and the important east-west line that bounds Washoe Valley on the south; the third occurs between the second and the northeast-southwest fault at the southwest corner of Washoe Valley. The fourth block lies to the south of the third, and may be considered as extending to the south limits of Little Valley. Block 1 has been relatively elevated and a part forced westward. Block 2 is lowest of all. Block 3 has suffered differential elevation, with tilting to the north and a movement of its south end to the eastward. Block 4 has likewise suffered differential elevation, with a partial rotation of its north end to the east. This differential elevation has been effected not by tilting but by a series of step faults, with maximum rise at the south end. The peculiarities of the floor of Little Valley have been described, but a few of these need emphasis. An east-west section across the valley just north of Franktown shows the plateau surface extending unbroken to the foot of the high west scarp. The valley structure here consists of but the one main north-south fault, and a true valley does not exist. From this point south two faults diverge, the main one at the base of the high west scarp, and the other at the base of the comparatively low scarp on the east of the valley. The latter scarp is not continuous, but somewhat broken and irregular, due to the broken condition of the low east ridge itself. Furthermore, on the west side of this northern block there appear not one but two lines of longitudinal movements, as described before.

It is next to be noted on the map that the point at which the plateau remnant touches the foot of the high west scarp is just south of an east-west fault crossing block 1. South of this fault-line the sub-block has moved westward, and it is the northwest corner of this sub-block forced against the west scarp that has made the juxtaposition of this topographic element and the plateau remnant. From this point the two main fault-lines diverge for about a mile, when they become approximately parallel. Block 1 ends at the cañon of Franktown Creek. Along this fault-line the physiography indicates that the north side has moved relatively to the west and upward. The floor of north Little Valley, between the divergent fault-lines, is characterized by the

long, narrow granite blocks whose features have been given. They cannot be due to erosion, for they bear no fixed relation to drainage lines. The possibility of glacial action cannot be considered, for not only were glaciers absent here but also the seeming piles of granite boulders are solid rock beneath the surface covering, even though badly fractured. The aspect of this portion of Little Valley is as if it had been squeezed between powerful jaws, breaking the valley floor and forcing some small blocks broken therefrom above the general level. This is in entire harmony with the mode of formation of the valley presented later.

Block 2, opposite the central portion of Little Valley, seems to have suffered no differential elevation, but is broken by a cross-fault at about its center. North of the center line the axis of the block strikes east and north; to the south the strike is slightly east of north. The general crest line, however, parallels the high west ridge. The north end slightly overlaps the south end of block 1, and does not abut squarely against it. The fault-lines in this section of the valley are the same as to the north: one at the base of the high west ridge, and two on the west side of the plateau remnant on the low east ridge. All these lines are roughly parallel, so that the wide central portion of the valley is rectangular.

Block 3 has been elevated with respect to block 2, and also tilted a little to the north. The main line of east-west faulting, which bounds it on the north, is well shown in plate 27B by a prominent scarp and the group of andesite outcrops upon it. The block has moved eastward relative to block 2 and westward relative to block 4. The northeast-southwest fault separates blocks 3 and 4 in a precisely similar manner to the separation of blocks 1 and 2 by a parallel fault. The north end of block 4 swings to east of north, overlapping block 3 in the same way that block 2 laps 1.

Block 4, for the present purposes, may be considered reaching to the south limits of Little Valley. Actually, however, the southern portion of the block is broken by two-cross faults, along which the south walls have moved eastward. South of Little Valley lies another center of elevation, corresponding to Slide Mountain, whose culminating point is Snow Valley Peak.

On the west of Little Valley the same order of fault-block motion is recorded. From the Slide Mountain east-west fault south the high west ridge continues unbroken to the line of the important east-west fault. This first portion is, however, curved, with its concave side facing Little Valley. South of this line are a number of small blocks whose position is outlined in topographic forms. The Snow Valley Peak area is regarded as a solid block which has moved upward. The relatively sunken areas of Little Valley and Marlett Lake occupy portions between fault-blocks that have been spread apart laterally. The whole is very expressive of a compressive force acting between extreme north and south points. In fact, no other explanation seems adequate to explain the facts. Further, Slide Mountain and Snow Valley Peak represent elevated blocks, whose upward movement must have produced a compression in a north-south direction. Such force was necessary to produce the buckling of the low east ridge at the point west of Franktown where the plateau remnant abuts against the high west scarp, the shearing action that occurred at the two northeast-southwest faults, and the striking instance of the shortening of the high west ridge southeast of Incline. Also the fact that the two ridges bounding Little Valley are lowest at points midway between the centers of elevation of the same forces. There is strong supplementary evidence also of the compressive stress set up by the elevation of the two peak blocks, in the form and structural features of the hanging block in north Little Valley. This block, occurring at present as a series of small blocks, lies between the point where the plateau remnant east of north Little Valley abuts against the steep west scarp and a second point east of the upper entrance to Franktown Creek cañon. There is evidence of a plane of fracture at this point in the high west ridge, along which but little differential motion seems to have occurred. The south end of the hanging block is between 400 and 500 feet above the valley floor, so that at least that much of a cross-fault has occurred there to form this boundary of the block. The north end of the hanging block joins the low east ridge where the plateau remnant rests against the west scarp, thus proving the original identity of its level top with the old erosional sur-

face. In brief, the hanging block appears to be a remnant of the plateau left in its present elevated position by the downdropping of a triangular valley block adjoining it on the east. At the end of the second period of north-south faulting, this hanging block formed the west portion of the block just east of the high west ridge block. For the several crust blocks to have moved in the manner indicated it is evident that a compressive stress acted at the point where the plateau remnant meets the west scarp, and a tension existed within the valley, allowing the valley blocks to drop at their south ends while held unmoved at the north. This sort of a movement of the main valley block would tend, in conjunction with the certain amount of torsional stress that was almost certainly set up, to fracture the block along lines radiating from the fixed point, and cause differential movements among the small sub-blocks. This is precisely what seems to have happened in north Little Valley. In south Little Valley a similar downdropping of a valley block has occurred, except in the most southern portion, where differential elevation has been combined with step-faulting, to produce the valley. In this connection it is well to examine Marlett Lake rather in detail. An examination of the map shows that the block under the lake lies between three other blocks, two of which meet at an angle of about 135°. These two blocks occupy their present position because of the compressive stress in a north-south direction set up by the elevation of Snow Valley Peak. The result of the action of this force has induced a tensional east-west force through Marlett Lake block that allowed the latter to drop. This interpretation of the structure is based upon the assumption of normal faulting. This being so, it follows that for an earth-block to drop relatively to the ones adjacent a tensional force must have been in operation. The elevation of Snow Valley Peak, which did occur, must have provided a north-south compression if the faulting was normal, and an induced tension at right angles. The faulting of the region is characteristically normal in all its aspects. Further, had the conditions of stress necessary for thrust faulting obtained, with the steep position of its fault-plane great crushing of the rocks would have occurred rather than actual movement of large blocks. Lastly, the same

causes that produced the Marlett Lake *graben* acted to form the present Little Valley.

With the adoption of this origin of the valleys, the age of the northeast-southwest faults becomes fixed, and was contemporaneous with the first period of east-west movement, which produced Slide Mountain and Snow Valley Peak. No other hypothesis to account for the present valley appears at all able to fulfill the conditions. The character of the valley previous to the last important faulting is, however, not so clear. The structure was comparatively simple. The drainage was probably consequent, although some features of subsequent streams may have been developed by the coalescence of the several lateral creek branches flowing at the base of the high west scarp. But in any case, with the valley structure produced by the last faulting, the drainage became consequent, and Franktown Creek is an example of a longitudinal consequent stream in a young mountain range.

Summary of Sequence of Faults.

In the Little Valley area, then, where the relative ages of faults can be ascertained, the following sequence obtains. First and oldest was a period of north-south movements, which was surely accompanied by some secondary east-west faulting. The Nevada diastrophic valleys were formed at this period. Second, there was a period of north-south faulting, with secondary movements at right angles. The first Little Valley was formed at this time, though it may have been little more than a level area about a mile wide and six miles long at the base of the high west scarp. Third came a period of intense east-west faulting, with much superinduced motion along older fault-planes, and the formation of several marked northeast-southwest faults along which a shear occurred. The present Little Valley was established at this time. Fourth, there occurred further slight movement along the east-west planes, with probably some induced motion along other lines as well. The floor of Little Valley was somewhat modified, as a result. Warping and tilting in Washoe Valley likewise resulted from these latest differential rock movements. Still later but small movements along the old fracture planes have produced tilting of Washoe Valley to the east.

Eagle Valley and the northern part of Carson Valley have also experienced a similar tilting. These small diastrophic movements are probably still taking place.

It is easily possible to write a story of the faulting over the remainder of the area, but as all the details have not yet been gathered such a course would be of little value. There can be no question about the occurrence of the several periods of faulting elsewhere, however, and that the geomorphic evolution of the Tahoe basin is vitally and minutely connected with these movements, particularly on the east side. The work of translating this history still remains to be accomplished, and presents a very fascinating field for study.

OTHER IMPORTANT STRUCTURAL FEATURES ELSEWHERE.

There are a few suggestive structural features both on and just off the mapped area that deserve attention in this paper, both because of relation to the facts herein presented, and because of their presenting further unsolved problems connected with the geomorphogeny of the Sierra Nevada.

CARSON AND TRUCKEE RIVERS.

Some details of the history of the Carson River have been given, showing a tilting of a part of its valley to the east. A few more important features need to be given, and some similar characteristics of the Truckee River and its valley cited for the sake of comparison, to show the general nature of certain diastrophic movements. The old course of the Carson River has been shown to be along the base of the hills at the west of the valley, and that its present course is due to tilting of the valley to the east. In that part of north Carson Valley, a few miles west of Prison Hill, there are found the remains of three river terraces. The rough outlines of these are shown by dotted lines on the topographic map. Their elevations are respectively 5,250, 4,950, and 4,850 feet. The valley is at an elevation of 4,650 feet. Some of the difference in elevation of terraces and valley is due to faulting, as has been set forth; some appears due to the actual stream terracing. The material of all the terraces is gravelly,

lightest and finest on the lowest, with progressively more admixture of alluvium with decreasing elevation. It is possible that faulting is responsible for the three terraces, but no definite facts have been found to establish this. They are very suggestive of a series of small but distinct elevations of the Sierra in very late geologic time, comparable to the warping and tilting of Washoe Valley.

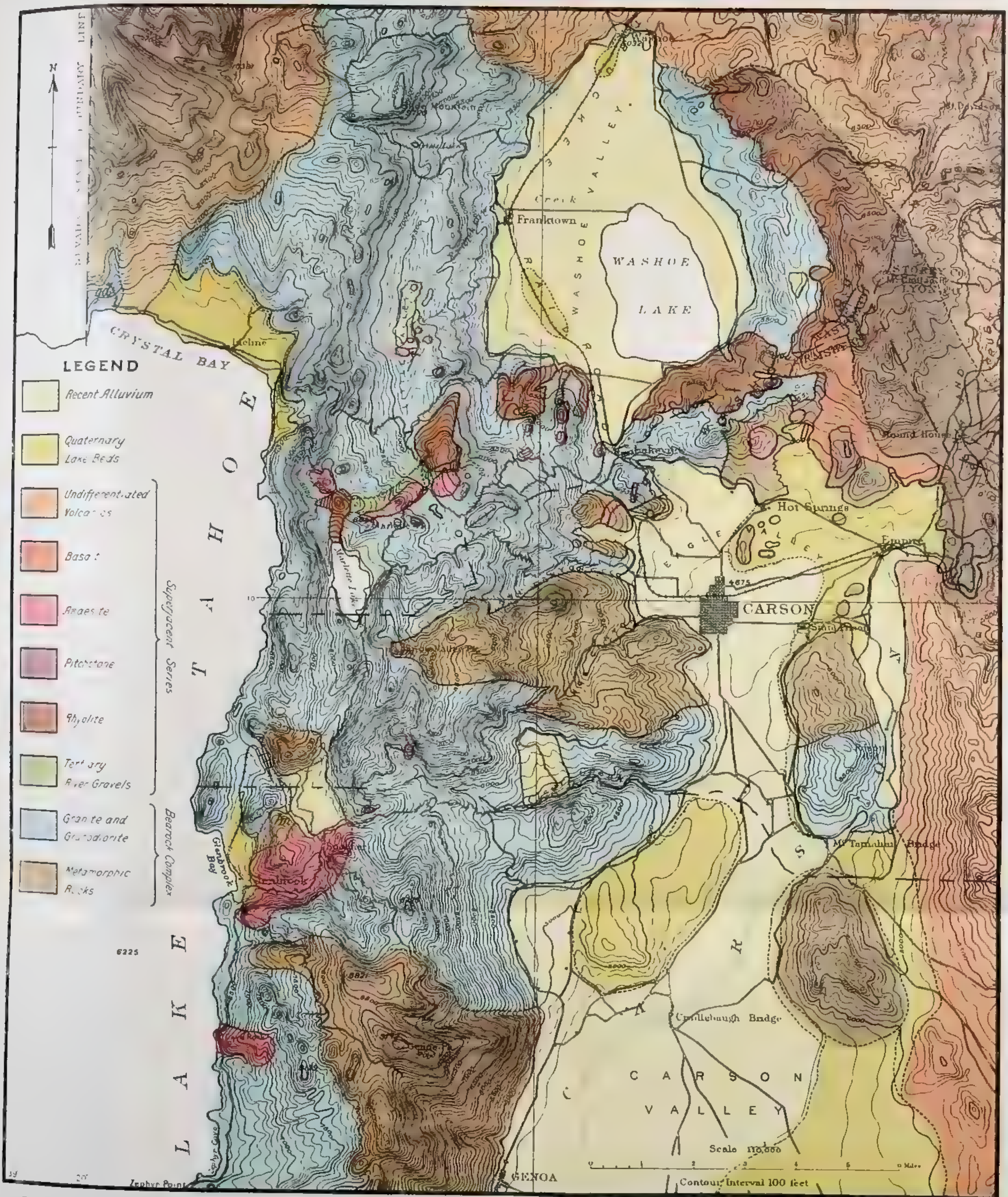
The second notable point concerning the Carson River is one relating to the Virginia-Pine Nut Range. Near Empire the river flows rather sluggishly before it enters its cañon; within the rocky gorge it is cutting in solid rock. A mile east of Empire, river gravels and deposits are found on the hillsides up to 300 feet above the river. The whole cañon has not yet been examined, but the known facts indicate an elevation of the range, with resultant downcutting of the river. The rocks here are largely volcanic and are eroded by the river at as rapid a rate as the elevation of the range.

In the Truckee Meadows north of the Carson quadrangle the terraces and antecedent stream features of the Truckee River are more marked than those of the Carson. There are three well-developed terraces west of Reno, besides a few smaller and obscure ones. The lowest has the angle of slope of the present river, while the others incline more steeply to the east, the higher having the greater grade. The two older terraces have been broken and displaced with the downthrow of twenty-five feet to the east by a north-south fault in the range south of the river. The upper terrace contains a vast amount of very coarse rock fragments, boulders five or six feet in diameter being not rare. It was probably formed in late glacial time when the river was transporting glacial morainal material from its cañon near Lake Tahoe. This indicates a late age for the faulting, coincident with the later periods of movement in the Carson area. The Truckee River flows almost due east across the meadows near Reno, and enters the Virginia Range in a manner similar to the Carson. But here exists evidence sufficient to establish the fact of elevation of the Virginia Range. For a mile before the river meets the mountains it flows very sluggishly in a deep channel bordered by swampy ground. West of this its grade is considerable and

its current swift, often torrential. In times of high water the low land just west of the Virginia Range becomes a lake. Upon entering its cañon in the Virginia Range the river resumes its rapid flow and downward cutting of the rocks of the bed. The conditions of deep, sluggish water changes to that of rapids over shallows within a few feet. The range here seems to be rising faster than the river is able to cut. The axis of greatest elevation appears to be a few hundred yards only within the cañon. At this line some river deposits exist above the present water-level, and some fresh-water shells are poorly preserved in a few thin beds. This may indicate an earlier axis of elevation to the east of the present one, with temporary damming of the river. These observations, and those relating to the Carson River, establish the slow elevation of the Virginia Range and the antecedent characters of the two streams. The terraces suggest a wealth of facts yet to be ascertained relating to the late Pleistocene and Recent geomorphic history of the region.

Transmitted May 5, 1910.

GEOLOGICAL MAP OF THE
TAHOE-CARSON AREA



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BY

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NOTE ON A GIGANTIC BEAR FROM THE PLEISTOCENE OF RANCHO LA BREA

BY

JOHN C. MERRIAM.

With the exception of a single tooth obtained by the writer during his first examination of the Los Angeles asphalt beds in 1906, no remains representing the bear family are known to have been obtained from Rancho La Brea until very recently. A few months ago Mr. Guintyllo, Assistant in Palaeontology at the University of California, called the attention of the writer to a small collection of foot-bones representing a gigantic bear, obtained by Mr. Eugene Fisher during the excavation work carried on for the University of California at Rancho La Brea. As the bones which have recently come to light seem to represent an animal of the same type as that suggested by the tooth found some years ago, it seems desirable to place on record the information available.

The tooth (figs. 1 and 2) obtained in 1906 is a very large lower canine, differing decidedly from the canine teeth of the carnivore species thus far described from Rancho La Brea. It is of extraordinarily large size, exceeding in dimensions the inferior canines of *Felix atrox bebbi* (the enormous lion of Rancho La Brea), *Arctotherium simum* (the cave bear of Northern California), and the gigantic Recent Alaskan bears. The crown of the tooth is short and thick, and the curve of the posterior border is more sharply marked than in most forms. It is thicker transversely and more strongly concave posteriorly than in

Felix atrox bebbi. In general the crown resembles that of the bears more closely than any of the other groups. The sharpness of the bend in the middle of the posterior border suggests

1 2

3

Figs. 1 and 2.—*Arctotherium californicum.* Inferior canine tooth, no. 10600. × ½. Fig. 1, outer side; fig. 2, inner side.

Fig. 3.—*Arctotherium californicum.* Metacarpal elements. Type specimen, no. 17754. ×½.

Arctotherium simum, but the tooth seems slightly larger and less slender than in that form. In the relative shortness and thickness of the crown it resembles some of the large Alaskan species

of *Ursus*, but is larger and less concave posteriorly than in the species at hand for comparison. The tooth may be referred tentatively to *Arctotherium*, as it approaches this genus more closely than to other forms.

The foot-bones available for study consist of metacarpals 1, 3, 4 and 5, and the pisiform. They exceed considerably in size the very largest known specimens of *Arctotherium simum* from Potter Creek Cave, California; and are also much larger than the largest specimens of the Recent Alaska bears available for study. In all elements present the form is nearer to that of *Arctotherium* than it is to that of *Ursus*, and the type seems definitely referable to *Arctotherium*. This individual differs from all of the specimens of *Arctotherium simum* available for study in the greater width and general robustness of the metacarpal elements. This is particularly true of metacarpal four, in which the shaft is relatively very wide, and shows but little median constriction. The rugosities on all of the elements are very pronounced, indicating that this individual was probably in advanced age.

Even when the element of age is taken into consideration, it seems improbable that this form could be classed in the same specific group with *Arctotherium simum*, of which no specimens in the collection from Potter Creek Cave are found to approach the Rancho La Brea form in size and robustness.

The tooth and foot specimens were obtained from two localities so far apart that there can be no possible suggestion that they represent the same individual. As both specimens have the characters of *Arctotherium*, and both represent an extraordinarily large and robust form, it is desirable for the present to refer to the Rancho La Brea type as a distinct species, which may be known as *Arctotherium californicum*. The elements of the foot, no. 17754, are taken as the type of the species.

Like the lion of Rancho La Brea, the bear described above represents one of the largest and most powerful known carnivores of Pleistocene time. The measurements of the specimens available are as follows:

METACARPALS, NO. 17754.

Metacarpal I, greatest length	86.8 mm.
Metacarpal III, greatest length	126.7
Metacarpal III, least transverse diameter of shaft	18.7
Metacarpal IV, greatest length	130.5
Metacarpal IV, least width	23.
Metacarpal V, greatest length	130.2

INFERIOR CANINE, NO. 10600.

Distance from tip of crown to base of enamel on posterior border	47.3 mm.
Anteroposterior diameter of crown 35 millimeters below tip	26.8
Transverse diameter of crown 35 millimeters below tip	21.4

A single metapodial from the collections obtained at Rancho La Brea resembles in form and dimensions the corresponding bone of *Arctotherium simum* from Potter Creek Cave.

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A COLLECTION OF MAMMALIAN REMAINS FROM TERTIARY BEDS ON THE MOHAVE DESERT

BY

JOHN C. MERRIAM.

Through the kindness of Mr. John R. Suman of the University of California, the writer has recently received an interesting collection of mammalian remains obtained by Mr. H. S. Mourning of Los Angeles, from deposits exposed in the Mohave Desert region, about ten miles northwest of Barstow, San Bernardino County, California. Mr. Mourning and Mr. Suman very kindly presented the collection to the University. This material is of especial interest as it represents a mammalian fauna which may serve as a basis for correlation with faunas of the well-known mammal-bearing epicontinental formations of the basin and great plains regions to the east, and may thus assist in determining the relation of the Tertiary geologic scale of California to that of the interior region.

As yet nothing is known regarding the nature of the formation in which the collection was obtained. According to a sketch map published by Hershey[1] the point at which the collection was made would fall within the limits of what is designated by Hershey as the Rosamond series. This series has not, however,

[1] Hershey, O. H., Univ. Calif. Publ. Bull. Dept. Geol., vol. 3, opposite p. 3. 1902.

been characterized in any way, so that the nature of the formation is unknown. As geographic location is one of the important factors concerned, the horizon at which this collection was obtained may be referred to under a geographic designation as the Mohave beds.

The collection presented to the University consists of about one hundred specimens representing teeth, portions of jaws, antlers, and foot-bones. The following forms are represented:

Merychippus, near *calamarius* (Cope)
Merychippus, sp. indet.
Merycodus necatus Leidy
Procamelus (?), sp.
Pliauchenia (?), sp.

The greater number of the horse remains represent a species related to *Merychippus calamarius* described by Cope from the Santa Fe Upper Miocene. The Mohave form is represented by teeth of a more advanced type than those in the Middle Miocene of the Mascall and Virgin Valley beds. The crowns (pl. 29, figs. 1*a* to 3*b*) are longer and somewhat larger in cross-section than any of the forms from the Mascall or Virgin Valley. They are, however, to be included in *Merychippus* rather than in any of the more advanced genera.

A worn tooth (pl. 29, fig. 4) in the collection differs enough in dimensions from the other specimens to suggest that it may represent a species, still more advanced than the one just described. It may, however, be included with the other forms.

A number of astragali (pl. 29, fig. 5) and phalangeal elements of the *Merychippus* type show considerable differences in size and form, and may represent more than one species.

The *Merycodus* remains consist of fragments of antlers evidently representing more than a dozen individuals. Several of these specimens are well enough preserved to show the shaft of the horn up to a point above the bifurcation (pl. 29, fig. 7). Other fragments show the terminal portion of the horn (pl. 29, fig. 6). The form represented in these specimens, as shown particularly in plate 29, figure 7, seems identical with that of *Merycodus necatus* Leidy of the Nebraska Upper Miocene. This

animal must have been a common form in the Mohave region in Upper Miocene time, judging by the relatively large number of specimens obtained.

The camel remains found comprise astragali and proximal phalangeal elements which seem to represent two species, one considerably larger than the other. The smaller form may represent *Procamelus*, the larger one *Pliauchenia*, but a satisfactory determination is not possible with the material at hand.

The common species of *Merycodus*, and the horse most abundantly represented in the collection, taken together indicate that the age of this fauna is approximately Upper Miocene. The camel remains do not negative this determination. It seems improbable that later collections will show sufficient material of a more primitive or less advanced type to indicate that this particular horizon is of Middle Miocene age. On the other hand, the absence of horses distinctly advanced beyond the *Merychippus* type indicates a period earlier than Pliocene.

As fragmentary as this collection is, the species included in it unavoidably sugests a close faunal connection with the great plains region during Upper Miocene time. It is also interesting to note that as yet no faunal phase of the Miocene corresponding to the Mohave stage is known in eastern Oregon or in northern Nevada; as also that there is reason to suppose that a cycle of erosion rather than of deposition was in progress in these regions in Upper Miocene time.

Transmitted February 24, 1911.

EXPLANATION OF PLATE 29.

Figs. 1*a* to 3*b*.—*Merychippus*, near *calamarius* (Cope). Ten miles northwest of Barstow, San Bernardino County, California.

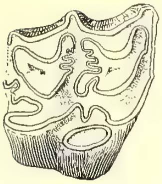
> Figs. 1*a*, 1*b*, and 1*c*.—Upper molar, no. 17370, natural size. Fig. 1*a*, occlusal view; 1*b*, anterior view; 1*c*, exterior view
>
> Fig. 2.—Upper molar with unworn cusps, no. 17371, natural size.
>
> Figs. 3*a* and 3*b*.—Lower molar, no. 18599, natural size. Fig. 3*a*, occlusal view; 3*b*, lateral view.

Fig. 4.—*Merychippus*, sp. indet. Worn upper molar, no. 18600, natural size. Ten miles northwest of Barstow, San Bernardino County, California.

Fig. 5.—*Merychippus* (?). Astragalus, no. 18601, natural size. Ten miles northwest of Barstow, San Bernardino County, California.

Figs. 6 to 8.—*Merycodus necatus* Leidy. Ten miles northwest of Barstow, San Bernardino County, California.

> Fig. 6.—Portion of a tip of an antler, no. 17375, natural size.
>
> Fig. 7.—Antler, no. 18602, natural size.
>
> Fig. 8.—Portion of an antler split through the fork, no. 17374, natural size.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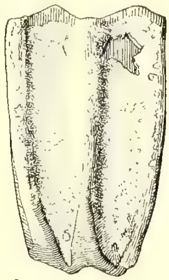
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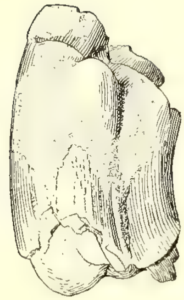
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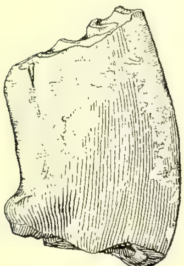
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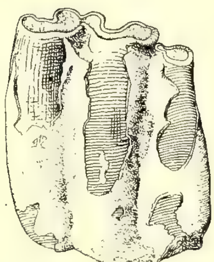
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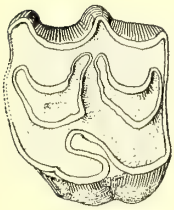
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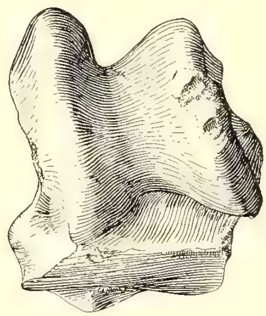
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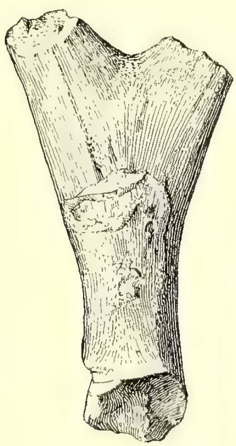
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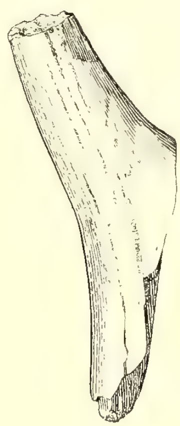
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BULLETIN OF THE DEPARTMENT OF
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Vol. 6, No. 8, pp. 171-177 Issued June 28, 1911

THE STRATIGRAPHIC AND FAUNAL RELATIONS OF THE MARTINEZ FORMATION TO THE CHICO AND TEJON NORTH OF MOUNT DIABLO

BY
ROY E. DICKERSON

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BY

ROY E. DICKERSON.

CONTENTS.

INTRODUCTION.

The Martinez formation was first described by Gabb[1] from beds supposed to be transitional between the Chico and Tejon groups. It was shown later by Stanton[2] to contain a fauna distinct from that of the Chico, but was referred by Stanton to the Tejon as a division of that group. In a study of the type locality for the Martinez group Merriam[3] came to the conclusion

[1] Gabb, W. M., Rep. Geol. Surv. of Cal., Palaeontology, vol. II, p. 13, op. preface, 1869.

[2] Stanton, T. W., The Faunal Relations of the Eocene and Upper Cretaceous on the Pacific Coast, 17th Rep. U. S. Geol. Surv., pp. 1011-1060, 1895-96.

[3] Merriam, J. C., The Geologic Relations of the Martinez Group of California at the Typical Locality, Jour. of Geol., vol. 5, pp. 767-775, 1897.

that the sharp separation of the Martinez fauna from that of the Chico and Tejon indicated that an unconformity certainly existed between the Martinez and Chico, and that sedimentation might have been interrupted between the times of deposition of the Martinez and the Tejon.

In the work on the Martinez formation carried on in past years by Gabb, Stanton, Merriam, and Weaver,[4] no locality was found at which the stratigraphic relations of this formation to the Chico and Tejon were clearly shown.

During the fall term of 1910, while working under the direction of Dr. Merriam, in a small area four miles north of Mt. Diablo, the writer has been fortunate enough to find a section in which the Martinez-Chico and Martinez-Tejon contacts are well exposed, and the Martinez seems clearly separated by unconformity from both the Chico and the Tejon. While this condition may be only local, it is interesting to find evidence of considerable time-intervals both preceding and following the deposition of the Martinez. The faunal relations between the Chico and the Martinez also illustrate strikingly the interruption of sedimentation.

NATURE OF CHICO, MARTINEZ, AND TEJON FORMATIONS IN THE AREA CONSIDERED.

The Chico formation in this region consists of a hard, dark, fine-grained sandstone with subordinate strata of dark gray limestone, which is interbedded with a shale and a soft buff sandstone containing numerous fragments of leaves and stems. It has a general east and west strike and dip of 60°-70° N, and contains a characteristic Chico fauna including *Meekia sella, Inoceramus,* sp., *Venus varians, Mytilus,* sp. (near *quadratus*), *Tellina mathewsoni, Pugnellus manubriatus, Cinulia obliqua, Helicoceras vermicularis, Ancyloceras,* sp.

The Martinez comprises a blue-gray, glauconitic sandstone and a sandy shale with thin strata of limestone. It has a general east and west strike and a dip varying from 35°-50° N. The

[4] Weaver, C. E., Contribution to the Palaeontology of the Martinez Group, Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, pp. 101-123, 1905.

fauna of this bed is represented by numerous well-preserved specimens. The following list of species corresponds closely to the fauna of the Martinez at the type locality.

MARTINEZ FAUNA NORTH OF MT. DIABLO.

	Chico	Martinez	Tejon
Flabellum remondianum		*	*
Trococyathus zitteli		**	
Cidaris, sp. (?)		√	
Anatina tyroniana (?)		√	
Cardium cooperi		*	†
Crassatella unioides		**	
Cucullaea mathewsoni		**	
Leda alaeformis		**	
Leda gabbi		*	*
Lima (?) *multiradiata*		**	
Lima (?) n. sp.		√	
Lucina (?) n. sp.		√	
Mactra (?) n. sp.		√	
Nucula truncata	*	*	*
Pholadomya nasuta		**	
Pectunculus veatchii, var. *major*		**	*
Tapes quadrata		**	
Tellina horni		*	*
Tellina undulifera		**	
Teredo, sp.		√	
Zirphaea, sp.		√	
Nucula, sp.		√	
Ampullina striata		**	
Anchura, n. sp. (*a*)		√	
Anchura, n. sp. (*b*)		√	
Brachysphingus liratus		*	*

* Common.

† Rare.

** Characteristic.

√ Unfixed.

MARTINEZ FAUNA NORTH OF MT. DIABLO.

	Chico	Martinez	Tejon
Cylichna costata	*	*	*
Dentalium cooperi	*	*	*
Discohelix, sp.		√	
Fusus, n. sp. (?)		√	
Galerus excentricus		†	*
Heteroderma, sp.		**	
Lunatia horni		†(?)	*
Neptunea mucronata		**	
Perissolax tricarnatus		**	
Turritella infragranulata		**	
Turritella pachecoensis		*	*(?)
Urosyca caudata		**	
Siphonalia lineata		**	
Surcula, n. sp. (*a*)		**	
Surcula, n. sp. (*b*)		**	

* Common.
† Rare.
** Characteristic.
√ Unfixed.

The Tejon is composed of white to dull red sandstone, coal strata in soft shales and sandstones, and a basal conglomerate, with a general east-west strike and a dip of 25°-35° N. *Unio* (?) *penultimus* and a leaf of a palm were found in the coal strata. *Amauropsis alveata*, *Trocosmilia striata*, *Morio tuberculatus*, *Tapes conradiana*, and *Turritella uvasana*, were found above the coal strata in white sandstone.

RELATION OF MARTINEZ TO TEJON.

The evidence of relationship of the Martinez to the Tejon formation is based (1) upon areal mapping of the beds containing characteristic faunas of these formations; (2) upon variation of strike at the contact of these formations; (3) upon variation in dip throughout the area studied; (4) upon the presence of a conglomerate which marks a very decided change in sedimentation at the base of the Tejon.

The Martinez formation is represented areally by a strip averaging one quarter of a mile wide which extends from lower Oil Creek westward for four miles. Its west end is terminated by a cross-fault, while its eastern end is cut off by the Tejon conglomerate.

Throughout the area studied there is a constant difference in strike between the Martinez and the Tejon. This is generally at least ten degrees, and in lower Oil Cañon it is much greater. This difference in strike causes the Tejon conglomerate to rest upon a stratum of hard Martinez sandstone at one locality and upon soft Martinez shales at another, which sufficiently accounts for a very irregular Martinez-Tejon contact. In lower Oil Cañon, a mile southeast of Stewartville, a basal conglomerate of the Tejon formation has a strike of N 45° W, while only a hundred feet away Martinez sandstone is found with a strike of N 90° W. There can be no doubt about the age of the sandstone as it contained the following characteristic species at this locality: *Heteroderma*, sp., *Trococyathus zitteli*, *Tellina undulifera*, *Urosyca caudata*, *Pectunculus veatchii*, var. *major*, *Neptunea mucronata*.

Professor Louderback, who has worked extensively in the Mt. Diablo quadrangle, has found Tejon fossils in the sandstone a few feet above and conformable with the conglomerate, so that the age of the conglomerate is certainly Tejon.

The dip of the Martinez throughout the field is greater than that of the Tejon. The basal Tejon conglomerate, which is from ten to twenty feet thick, rests upon the Martinez sandstones and shales and forms a well-defined bed for over four miles in length. It consists of very coarse pebbles and boulders, which make it easily separable from the sandstones of the Martinez. The pebbles and boulders are in most places quartzose, but fragments of fossiliferous limestone, and sandstone and igneous rocks of various kinds also occur. *Nucula truncata*, *Cylichna costata*, *Modiola cylindrica* (?), *Dentalium cooperi*, and *Zirphaea* (?) bored boulders which resemble very closely the *Zirphaea* (?) borings on the Martinez-Chico contact described below, have been obtained from limestone and sandstone boulders imbedded in the

conglomerate. Either the Chico or Martinez formations supplied this material, or possibly both may have contributed to this basal Tejon, as these species are limited to the upper Cretaceous and the Eocene on this coast.

RELATION OF MARTINEZ TO CHICO.

The evidence of relationship of the Martinez to the Chico is based (1) upon the areal mapping of the beds containing characteristic faunas of these two formations; (2) upon the variation of dip and strike at the contact; (3) upon a pre-Martinez fault in the Chico; (4) upon a sudden and complete change from Chico to Martinez fauna at he contact; (5) upon the presence of a line of boring molluscs (*Zirphaea*) (?) which have penetrated the Chico along the line of contact.

The strike of the Chico and Martinez throughout most of this field is approximately the same. One marked variation occurs in lower Oil Cañon, where the strike of the Chico is N 75° W, while that of the Martinez which rests upon it is N 90° W. A few hundred feet west the Chico has a strike N 90° W. Detailed work shows that the Chico is faulted here and that the contact between the Chico and Martinez is directly traceable across this fault, thus proving the pre-Martinez age of the fault.

One mile south of Stewartville a sharp contact between the Chico and Martinez was found. The Chico sandstone has a dip of 65° N, while the gray conglomeritic Martinez sandstone has a dip of only 45° N. Immediately below the contact this Chico sandstone contains the folowing fauna: *Meekia sella, Tellina mathewsoni, Inoceramus*, sp., *Cypraea*, sp., *Scalaria*, sp., and a shark's tooth. Ten feet below the contact the Chico forms *Helicoceras vermicularis, Cinulia obliqua*, and *Tellina*, sp. were found in a dark gray limestone.

From six inches to ten feet above the contact at the abovementioned locality the following Martinez species were collected: *Tellina undulifera, Ampullina striata, Turritella infragranulata, Arca biloba, Urosyca caudata, Cucullaea mathewsoni, Pectunculus veatchii*, var. *major, Siphonalia lineata, Lima*, n. sp. (?),

Leda gabbi, Turritella pachecoensis, Flabellum remondianum, Galerus excentricus, Cylichna costata, and *Dentalium cooperi.* The first nine are characteristic of the Martinez, while the rest are also found in the Tejon. The last two are the only ones occurring in the Chico as well as in the Martinez and the Tejon.

For a half-mile the contact between the Chico and Martinez at the locality south of Stewartville is defined by abundant and clearly marked borings of *Zirphaea* (?). These borings are in Chico sandstone and limestone, but they are filled with material entirely different from the rock which is penetrated by them. There seems to be no question that the borings mark the shore line of the Martinez sea as it encroached upon a land surface formed of elevated and eroded Chico rocks.

Transmitted February 1, 1911.

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ARTHUR S. EAKLE

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NEOCOLEMANITE

Occurrence.—A deposit of calcium borate occurs at the head of a valley about five miles northwest of Lang, a station of the Southern Pacific railway in Los Angeles County, which is owned and now mined by the Sterling Borax Company of Los Angeles. The borate is known as colemanite and in its chemical composition and general physical properties it agrees with the colemanite from the Death Valley and Calico districts, but in its optical and crystallographical properties it is somewhat different, so the name *neocolemanite* is proposed to distinguish it as a variety of colemanite.

The mineral occurs as a stratified deposit, the strata alternating with layers of black carbonaceous shales, and the main seam of the solid mineral is from six to ten feet thick. A northern uplift has tilted the deposit so that the bands of mineral and shale stand almost vertical, the dip being about 80° south. The shales underlying the mineral layers are of considerable thickness, while above the deposit are heavy bedded sandstones. These sandstones show efflorescences of white alkali salts along their seams and bedding planes.

The shafts and mining operations are carried down on the main seam of the mineral and they are now down 250 feet with no apparent change in the dip or width of the bed. The lateral extent of the deposit is not yet determined, but it is evident that an extensive deposit of the pure borate exists. A narrow-gauge road connects the mine with Lang and all of the material is hauled to this station and shipped to Chicago and San Francisco. The poorer grade is separated from the gangue and impurities by calcination at the mine and then shipped in sacks.

Origin of the deposit.—The bedded character of the deposit is evidence that the mineral crystallized from an evaporating solution and that precipitations of both the borate and some of the silt which formed the shales took place. The solution filled a closed basin as a lake or marsh, probably similar to the alkali marshes of the desert regions. It is generally characteristic of such deposits that salts of various kinds, often in alternating

series, especially carbonates and sulphates of lime and soda, make up the deposit, and the well-known Searles Borax Lake in San Bernardino County, with its many associated minerals, is a good illustration of a desert formation. The Lang deposit, however, is an exception, as the neocolemanite is practically unaccompanied by other minerals except howlite, which is a silico-colemanite, and some calcite. Waters emptying into the basin could not have been charged with mixed alkali salts.

It seems probable that the original site of the deposit was a marsh containing marl and calc tufa with mud and considerable organic growth, and that later waters charged with boracic acid flowed into the basin and converted the carbonate of lime into the borate. Some and perhaps the greater part of the argillaceous material which forms the shales was precipitated by the decomposition of the impure limestone, together with organic matter. The carbon dioxide set free may not wholly have escaped, but possibly became occluded in the mud and later converted into carbon. Most of the borate is of a blackish gray color, due to impregnations of carbon along the cleavages and fractures. The conversion of the limestone into the borate in all probability took place before the overlying sandstones were formed. The absence of soda compounds and the presence of abundant plant life indicate that the lake or marsh was fresh into which springs containing boric acid discharged. The deposit later became submerged and the sandstones were laid down.

The origin of the boric acid is presumably volcanic and the springs probably issued from vents in the immediate vicinity of the basin. The deposit is situated in a hilly district and is partly surrounded by high masses of volcanic tuffs and rhyolites. The subsequent tilting of the deposit was not accompanied by heat or pressure sufficient to modify the borate materially, yet the mineral shows lines of strain and columnar partings due to pressure and shrinkage. The fissile shales owe their solidity to this slight pressure, and carbonization to some extent was also the result. The reduction of the occluded carbon dioxide may have been brought about through the decomposition of organic material deposited in the basin. There is, of course, the possi-

bility that all of the carbon in the deposit is from organic matter, the CO_2 of the carbonate escaping, as some of the shales are quite bituminous.

Structure of the mineral.—The neocolemanite is massive crystalline with a very glassy luster and eminent clinopinacoidal cleavage. It has also a distinct basal cleavage, yet does not part readily in this direction. This basal cleavage can be seen as lines on the clinopinacoid and is a very important help in the proper orientation of the crystals, because the angles for the positive faces are quite similar to those for the negative. The clinopinacoidal cleavage is so prominent that practically all of the mineral comes from the mine in cleaved fragments and cleaved masses. Specimens with a divergent columnar structure, the columns curving into fan-like shapes, are frequently found. A peculiar fibrous form of the lime borate with a satin luster occurs in the main shaft, which strongly resembles satin-spar. Crystals are comparatively rare and only a few good specimens were obtainable.

Crystal habits.—The crystals occur thickly grown together and firmly attached to the massive mineral. In general they are so attached that either the right or left half of the crystal can be seen. They range from several millimeters to more than a centimeter in width. Three distinct habits occur, each on a distinct type of the massive material. Crystals of Habit 1 are large, white, and translucent, lining the inner surface of a geode. They are the simplest type of the crystals, consisting mainly of the combination of the unit prism (110) and the clinodome (011). This habit is shown in figure 1, plate 30. Habit 2 is more common. The crystals are pale brown and nearly transparent, and possess the largest combination of forms. The predominating forms are the unit prism and clinodome, like in Habit 1, but the ends of the *b*-axis are invariably terminated by a group of small faces, as seen in figure 2. A more general combination of forms on this type is shown in figure 3. Habit 3 is totally dissimilar to the others. The crystals are white or colorless, occurring in small cavities in a white and coarsely granular variety of the mineral. In this habit the unit prism is elongated vertically and terminated

by the two faces of a low negative pyramid ($\bar{2}23$). Other forms are also present on most of the crystals but are much subordinate in size. This habit is shown in figure 4.

Forms.—Crystals of colemanite from Calico and Death Valley have been described by Jackson[1] and also by the writer[2] and about fifty forms have been determined for that mineral. The neocolemanite has eighteen forms and seven of them have no correspondence on colemanite. These seven forms are represented by excellent faces and most of them are common for the type. Readings were also obtained for other faces from which no satisfactory symbols could be deduced, so they are not included. The forms are arranged in the list below, those not found on colemanite being designated by an asterisk.

Letter	Symbol		Letter	Symbol		Letter	Symbol	
	Gdt.	Miller		Gdt.	Miller		Gdt.	Miller
c	0	001	κ	01	011	$\mathfrak{o}$	+ 2*	221
b	0 ∞	010	$\mathfrak{a}$	02	021	$\mathfrak{q}$	— 6*	$\bar{6}61$
a	∞ 0	100	*h*	—20	$\bar{2}01$	*v*	— 2	$\bar{2}21$
t	2 ∞	210	*W*	—30	$\bar{3}01$	$\mathfrak{w}$	— $\frac{2}{3}$*	$\bar{2}23$
m	∞	110	$\mathfrak{e}$	+24*	241	*o*	—21	$\bar{2}11$
$\mathfrak{l}$	∞ $\frac{3}{2}$*	230	$\mathfrak{r}$	+23*	231	$\mathfrak{b}$	—$\frac{2}{3}$2*	$\bar{2}63$

The base and front pinacoid are very narrow when present, one of the brown crystals only being an exception, where the *b*-axis was elongated and the faces were wide. The natural faces of (010) are small and narrow.

The prism (210) is always a line face. The prism (230) occurs only on the brown crystals and is a common form.

The clinodome (011) is broad and often has a wavy structure. The dome (021) is a common form only on the brown crystals.

Of the two negative orthodomes, ($\bar{3}01$) is fairly common while ($\bar{2}01$) was observed only on crystals of Habit 2.

[1] A. W. Jackson. On the morphology of Colemanite. Bull. Cal. Acad. Sci., vol. 2 (1885), p. 3.

[2] A. S. Eakle. Colemanite from Southern California. This bulletin, vol. 3, no. 2 (1902).

The form (241) is common to the crystals of all three habits, and the forms $(\bar{2}23)$ and $(\bar{2}63)$ are common forms on Habits 2 and 3, but were not observed on crystals of Habit 1. The steep negative pyramid $(\bar{6}61)$ is represented by one broad face on a brown crystal. The other pyramids are fairly common.

Referring to the gnomonic projection of the forms and zones as shown in plate 31, figure 6, it will be seen that the two zones of pyramids are missing where the values of $\mathbf{p}_0 = +1$ and -1, whereas in colemanite these two zones are well developed. On the other hand, the zone with $\mathbf{p}_0 = +2$ occurs on neocolemanite and is missing on colemanite. There is also the additonal zone with $\mathbf{p}_0 = -\frac{2}{3}$, on these crystals.

Measurements of the crystals.—The two-circle goniometer was used for the measurements, and practically all of the readings were good. It was evident from the first crystal measured that the angles ϕ and ρ for the clinodomes and base were greater than those for colemanite, indicating that the vertical axis was longer and the forms steeper. This variation was constant for all crystals and the lowest values of ϕ and ρ were higher than the greatest values for the corresponding faces on colemanite.

Ten good crystals were chosen for the measurements and below is a table containing the number of measurements of each form, the averages of the readings, and the calculated values from the axial ratio determined. For comparison the calculated values of ϕ and ρ for colemanite for corresponding forms as determined by the writer[3] and by Goldschmidt[4] from Jackson's measurements, are also included.

[3] *Loc. cit.*

[4] V. Goldschmidt. Krystallographische Winkeltabellen.

No. of Meas.	Neocolemanite							Colemanite			
	Gdt.	Miller	Measured		Calculated			Eakle		Goldschmidt	
			ϕ	ρ	ϕ	ρ		ϕ	ρ	ϕ	ρ
9	0	001	90°00′	21°40′	90°00′	21°40′		90°00′	20°07′	90°00′	20°13′
20	0 ∞	010	0 00	90 00	0 00	90 00		0 00	90 00	0 00	90 00
9	∞ 0	100	89 58	90 00	90 00	90 00		90 00	90 00	90 00	90 00
31	∞	110	54 09	90 00	54 10	90 00		53 53	90 00	53 57	90 00
12	2 ∞	210	70 08	90 00	70 08	90 00		69 58	90 00	70 00	90 00
10	∞ $\frac{3}{2}$	230	42 41	90 00	42 43	90 00		....	....	....	....
9	02	021	19 58	49 22	19 53	49 26		18 38	48 54	18 57	48 50
19	01	011	35 53	34 07	35 53	34 08		34 00	33 13	34 13	33 13
4	—30	$\bar{3}01$	$\overline{90}$ 00	62 00	$\overline{90}$ 00	62 02		$\overline{90}$ 00	61 49	$\overline{90}$ 00	61 47
1	—20	$\bar{2}01$	$\overline{90}$ 00	48 15	$\overline{90}$ 00	48 20		$\overline{90}$ 00	48 18	$\overline{90}$ 00	48 14
15	24	241	41 10	71 09	41 08	71 04		....	....	....	....
5	23	231	49 20	68 25	49 20	68 25		....	....	....	....
13	2	221	60 12	65 43	60 12	65 40		....	....	....	....
1	— 6	$\bar{6}61$	$\overline{51}$ 32	79 39	$\overline{51}$ 39	79 21		....	....	....	....
7	— 2	$\bar{2}21$	$\overline{45}$ 52	57 31	$\overline{45}$ 40	57 32		$\overline{45}$ 56	57 22	$\overline{45}$ 58	57 18
9	— $\frac{2}{3}$	$\bar{2}23$	$\overline{16}$ 47	20 50	$\overline{16}$ 42	20 55		....	....	....	....
9	—$\frac{2}{3}$2	$\bar{2}63$	$\bar{5}$ 24	47 47	$\bar{5}$ 42	47 53		....	....	....	....
2	—21	$\bar{2}11$	$\overline{63}$ 59	51 21	$\overline{63}$ 57	51 22		$\overline{64}$ 11	51 16	$\overline{64}$ 12	51 12

The pole of the crystals is almost midway between the normals to the base and rear dome ($\bar{1}01$), consequently the angles for positve terminal faces are quite similar to those for negative faces. If the neocolemanite is reversed in position so that all of the positive forms become negative and *vice versa*, then the readings would correspond closer to those for forms on colemanite, and only the forms (230), ($\bar{6}61$), ($\bar{2}23$) and ($\bar{2}63$) would be new, they becoming respectively (230), (561), (123), and (163). There would also be more correspondence in the optical orientation. However, the two minerals have a similar basal cleavage and it was by this cleavage that the crystals were oriented.

Determination of the polar elements.—The method of determining the values of $\mathbf{e}'$, μ, β, $\mathbf{p}'_0$, $\mathbf{q}'_0$, $\mathbf{e}$, $\mathbf{p}_0$, and $\mathbf{q}_0$ is fully explained in the author's paper on colemanite, so will not be repeated here. The average of nine direct measurements on the base gave $\rho = 21^\circ\ 41'$; $\mathbf{e}' = \mathrm{tg}\rho = .3973$. Since $\mathbf{e}' = \mathrm{cotg}\mu$ then $\mu = 68^\circ\ 20'$ and $\beta = 180 - \mu = 111^\circ\ 40'$. An average of twenty-eight readings on the clinodomes gave $\mathbf{e}' = .3973$, thus agreeing with the direct measurements.

The average of sixty-seven measurements gave $\mathbf{p}'_0 = .7606$, and an average of ninety-five measurements gave $\mathbf{q}'_0 = .5492$.

The values of these elements are therefore:

$$\mathbf{e}' = .3974;\ \mu = 68^\circ\ 40';\ \mathbf{p}'_0 = .7606;\ \mathbf{q}'_0 = .5492.$$

Since the mineral is monoclinic, the polar elements $\mathbf{e}$, $\mathbf{p}_0$, and $\mathbf{q}_0$ are obtained by multiplying the values $\mathbf{e}'$, $\mathbf{p}'_0$, and $\mathbf{q}'_0$ by the sin μ. The polar elements become therefore:

$$\mathbf{e} = \mathbf{.3692};\ \mathbf{p}_0 = \mathbf{.7069};\ \mathbf{q}_0 = \mathbf{.5104}.$$

Axial ratio.—The length of the axes c and $\grave{a}$ can be derived from the equations $c = \mathbf{q}'_0$ and $\grave{a} = \frac{\mathbf{q}'_0}{\mathbf{p}_0}$.

The axial ratio therefore for neocolemanite becomes:

$$\grave{a} : b : c = 0.7771 : 1 : 0.5492;\ \beta = 111^\circ\ 40'.$$

For colemanite the axial ratio is

$\grave{a} : b : c = 0.7768 : 1 : 0.5430;\ \beta = 110^\circ\ 07'$. Eakle.
$\grave{a} : b : c = 0.7755 : 1 : 0.5415;\ \beta = 110^\circ\ 13'$. Goldschmidt.

Optical orientation.—Neocolemanite is optically positive and the plane of the optic axes lies normal to the clinopinacoid as with colemanite, but in neocolemanite the axis of least elasticity makes an angle of about 42° with the vertical axis in the acute angle μ, whereas in colemanite this axis is inclined about 83° from the vertical in the obtuse angle β. The position of the acute bisectrix, determined with sodium light is as follows:

Neocolemanite	$\mathfrak{c} \wedge c = -42^\circ\ 30'$.	
Colemanite	$\mathfrak{c} \wedge c = +83^\circ\ 44'$.	Hiortdahl.[5]
	$\mathfrak{c} \wedge c = +82^\circ\ 34'$.	Bodewig and vom Rath.[6]

Indices of refraction.—The indices of refraction were determined with the "Abbe Totalreflectometer," using sodium light.

[5] Th. Hiortdahl. Colemanit, ein krystallisirtes Kalkborat aus Californien. Zeitschr. für Kryst., 10 (1884), 25.

[6] C. Bodewig und G. vom Rath. Colemanit aus Californien. *Ibid.*, 179.

They vary somewhat from those obtained by Mülheims[7] for colemanite.

Neocolemanite	$\alpha = 1.58185$;	$\beta = 1.58746$;	$\gamma = 1.60984$;	$\therefore 2V = 54° 36'$
Colemanite	1.58626;	1.59202;	1.61398;	$\therefore 2V = 54° 52'$

The optic angle measured with sodium light gave for neocolemanite

$$2E = 95° 22'; \; 2V = 55° 32'$$

Chemical composition.—The analysis of the mineral shows that it does not differ from colemanite in composition, so the indicated morphotropy in the vertical direction is not due to a chemical replacement or change. The variety is simply an allotropic modification of colemanite brought about by a possible difference in the mode of crystallization.

In the analysis of the neocolemanite the boric oxide was determined by titration with standard sodium hydrate, using mannite to set free the boron. The calcium was determined both gravimetrically and volumetrically.

Analysis:

B_2O_3	49.45%
CaO	27.76
H_2O	22.48
	99.69

Specific gravity $= 2.423$ at 13° C.

HOWLITE

Occurrence.—The silico-borate of lime occurs in considerable quantity in the deposit, as large and small nodular masses embedded in the layers of the lime borate. The mineral is very compact with a fine flaky structure and a snow-white color. Black streaks of carbonaceous matter ramify through much of the compact round masses. The layers of neocolemanite are bent and curved around the knotty lumps of howlite, which appear like "Augen" in the banded borate. The surfaces of some of the nodules have a botryoidal structure, but no crystals have been found.

[7] A. Mulheims. Colemanit von Californien. Zeitschr. für Kryst., 14 (1888), 230.

The mineral is soft and crushes easily to crystalline flakes and flour with no gritty particles. It is easily fusible, and completely soluble in dilute acid, yielding gelatinous silica on evaporation. Unlike colemanite or neocolemanite, it does not calcine to a white powder and cannot therefore be so readily separated from the gangue and carbonaceous impurities.

Origin of the mineral.—It is evident from the position of these masses of howlite in the deposit that the silico-borate was formed from the same evaporating solution and simultaneously with the crystallization of the neocolemanite. Granted that the original mineral was a siliceous travertine or marl acted upon by boracic acid then some of the silica became dissolved and formed metasilicic acid, which replaced the water of crystallization and boric acid that would otherwise have formed the neocolemanite. These nodular masses of howlite probably represent silico-borate segregations in the solution similar to magmatic segregations in the fused rock mass.

The similarity of the two minerals is more apparent if we express their composition as follows:

Neocolemanite	$Ca_2B_4O_8$ ·	$2B(OH)_3$ ·	$2H_2O$
Howlite	$Ca_2B_4O_8$ ·	$B(OH)_3$ ·	H_2SiO_3

It would seem from this that the howlite was formed in the presence of silicic acid which was taken up in the place of water and boric acid, and the resultant silico-borate was precipitated more rapidly as finely crystalline masses.

Chemical composition.—The mineral was dissolved in dilute hydrochloric acid, the boron expelled by evaporation with methyl alcohol, and the silica and calcium determined gravimetrically. The boric oxide was obtained in the same way as in neocolemanite. The average analysis showed

B_2O_3	45.56%
CaO	28.26
SiO_2	14.81
H_2O	11.37
	100.38

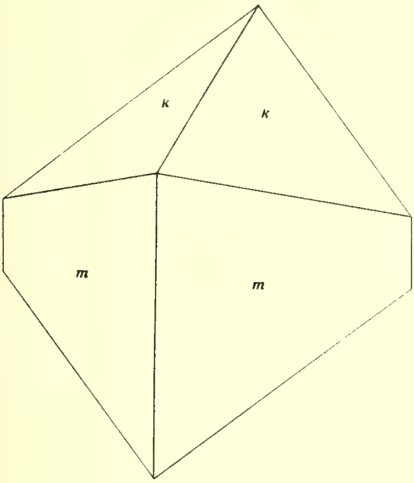
Specific gravity at 13° C = 2.531.

Associated calcite.—Specimens containing veins of crystallized calcite were recently collected from the main shaft by R. M. Wilke and kindly sent me. The mineral is both yellow and colorless, and the crystals exhibit three types of combinations. Most of the crystals are slender prisms terminated by rhombohedral faces. One type consists simply of the prism $(10\bar{1}0)$ and striated faces of the low rhombohedron $(01\bar{1}2)$. A second type shows the prism capped by large striated faces of the steep negative rhombohedron $(09\bar{9}5)$, narrow faces of $(01\bar{1}2)$, very narrow faces of the unit rhombohedron $(10\bar{1}1)$, and a small triangular base (0001). The third type shows the prism capped by perfect faces of the unit rhombohedron $(10\bar{1}1)$ and striated faces of the negative rhombohedron $(02\bar{2}1)$, the two being in about equal development.

Mineralogical Laboratory,
University of California.

Transmitted March 9, 1911.

1



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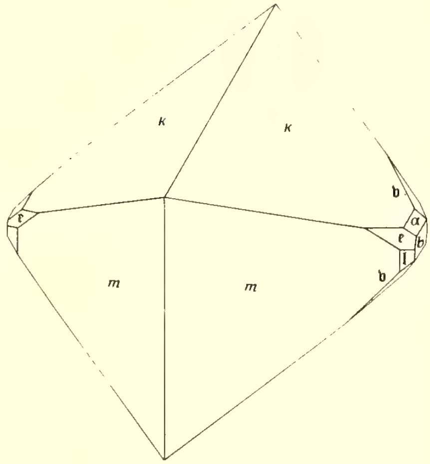

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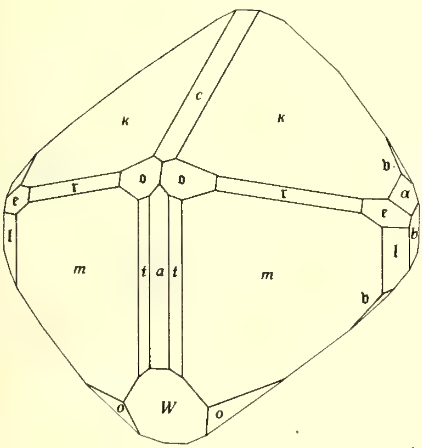

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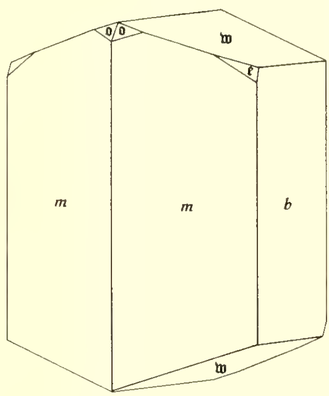

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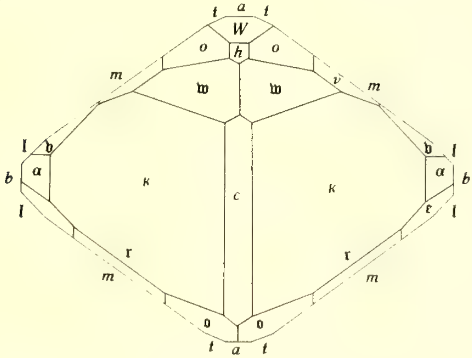
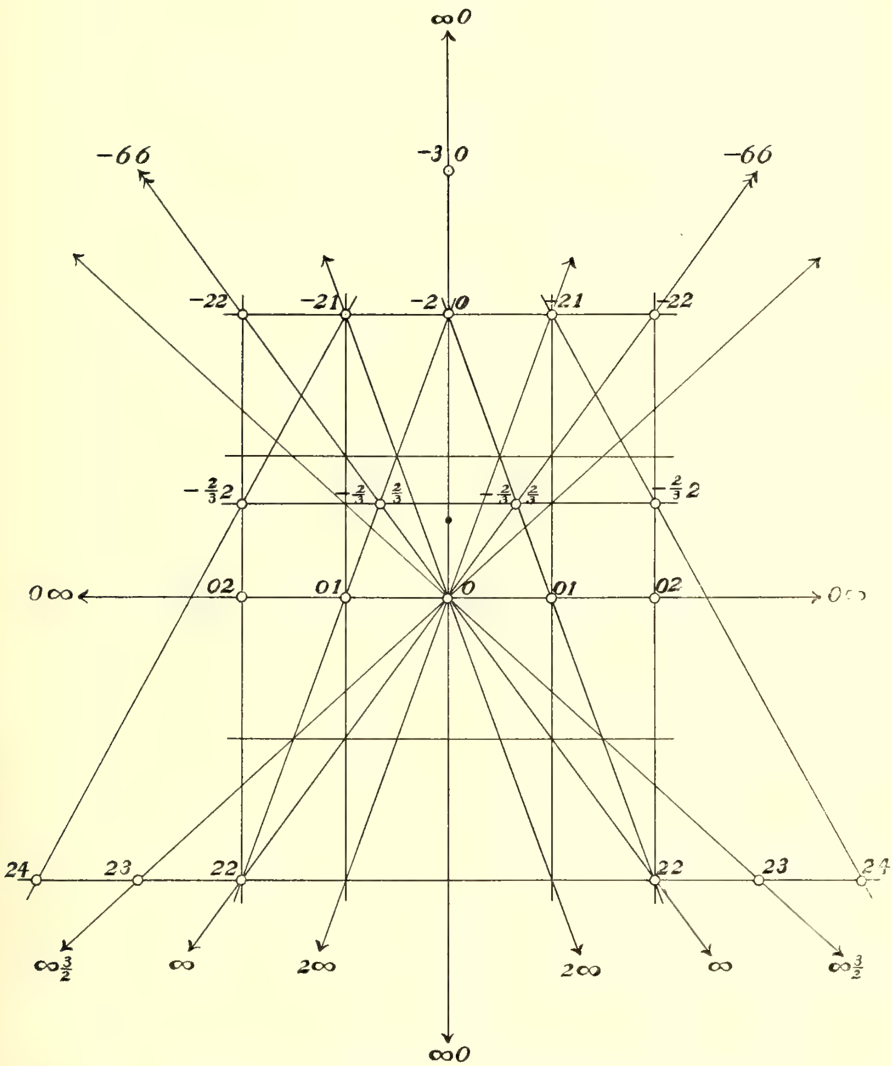


NEOCOLEMANITE FROM LANG, CALIFORNIA.

6



GNOMONIC PROJECTION OF NEOCOLEMANITE.

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A NEW ANTELOPE FROM THE PLEISTOCENE OF RANCHO LA BREA

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WALTER P. TAYLOR

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INTRODUCTION

Among the specimens in the collection of the University of California from the Pleistocene of Rancho La Brea are a number of fragments representing a very small antelope-like form which has not been recognized heretofore in the Pleistocene of the Californian region. The characters of the dentition indicate that this species is probably referable to the genus *Capromeryx* described by W. D. Matthew from the Pleistocene of Hay Springs, Nebraska.

The material available comprises three imperfect lower jaws, a number of metapodials, mostly posterior, two phalanges, and an astragalus. These were all found close together in the fossil beds, and presumably pertain to the same species. It is highly probable that certain of the elements mentioned belong to one individual, but of this it is impossible to be certain.

Few antelope-like artiodactyls have been obtained in North America. The presence in the Miocene and early Pliocene of the genus *Merycodus*, so peculiarly combining the characters of the antelopine and cervine groups in that it possesses hypsodont teeth but deer-like horns, naturally suggests that more typical antelopes might be expected in the later Pliocene and Pleistocene.

The Recent prong-horn, *Antilocapra americana*, has been

found fossil in the "lead region of Illinois, Wisconsin, and Iowa," and in the Hay Springs deposits on the Niobrara River, Nebraska, all of which are of Pleistocene age.

In 1902[1] Matthew described an animal from the Hay Springs fossil beds mentioned above, which appeared to be related to *Merycodus* and to *Antilocapra.* This form he named *Capromeryx furcifer,* referring it to the Merycodontidae.

Neotragocerus improvisus,[2] described by Matthew and Cook from the Snake River formation of western Nebraska, represents the existing Eurasian and African tragocerine division of the antelopes.

American representatives of the strepsicerine or twisted-horned group of antelopes were recently discovered by J. C. Merriam[3] in the Thousand Creek beds of northern Nevada and described as *Ilingoceros alexandrae. Sphenophalos nevadanus,* found with *Ilingoceros,* while "not far removed from the tragelaphine forms of the Thousand Creek fauna," is not clearly referable to any of the existing subdivisions of antelopes.

The fossil material representative of antelopes in North America being so exceedingly scanty, additional interest attaches to each new fragment.

DESCRIPTION

CAPROMERYX(?) MINOR, new species

Jaws and Dentition.—Jaw very much smaller than that of *Antilocapra americana* of slightly greater age. The specimen of prong-horn at hand (no. 8299, Calif. Mus. Vert. Zool.) still retains the milk dentition, but its molars are further advanced than in *Capromeryx.* The length of one of the portions of the jaw of *Capromeryx(?) minor* (no. 12523) is 55 mm.; while a roughly corresponding one of *Antilocapra americana* is 170 mm. The dimensions indicate that the present species is about the same size relative to the size of the prong-horn as is *Capro-*

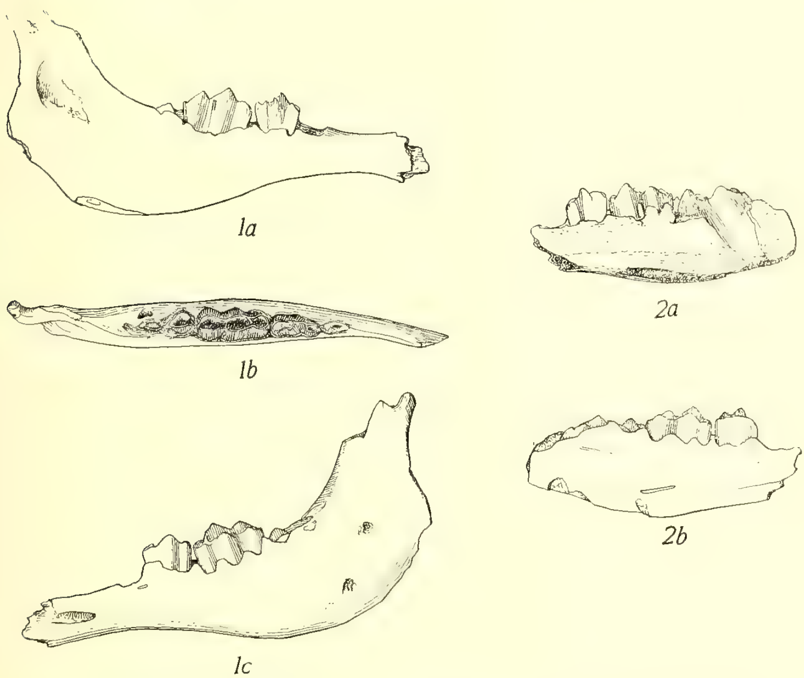
[1] Bull. Am. Mus. Nat. Hist., vol. 16, 1902, p. 317.

[2] Bull. Am. Mus. Nat. Hist., vol. 26, 1909, pp. 361-414.

[3] Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 320, 1909.

meryx furcifer, which is said to be two-thirds the size of *Antilocapra*.

Milk P_3 of the new form is primitive, resembling P_3 of *Merycodus* in that the anterior valley of its inner surface is entirely open toward the inner side, but more advanced than *Merycodus* in that the posterior valley is closed. This may indicate an advance in specialization, but it is difficult to say definitely, since milk and permanent teeth are the ones compared. The degree of hypsodonty of the teeth is like that of *Antilocapra*, being far in advance of *Merycodus*.



Figs. 1*a* to 2*b*.—*Capromeryx* (?) *minor*, new species. Rancho La Brea, near Los Angeles, California.

Figs. 1*a*, 1*b*, and 1*c*.—Jaw, no. 12523, natural size. Fig. 1*a*, internal aspect; 1*b*, superior aspect; 1*c*, external aspect.

Figs. 2*a* and 2*b*.—Jaw, no. 12817, natural size. Fig. 2*a*, internal aspect; 2*b*, external aspect.

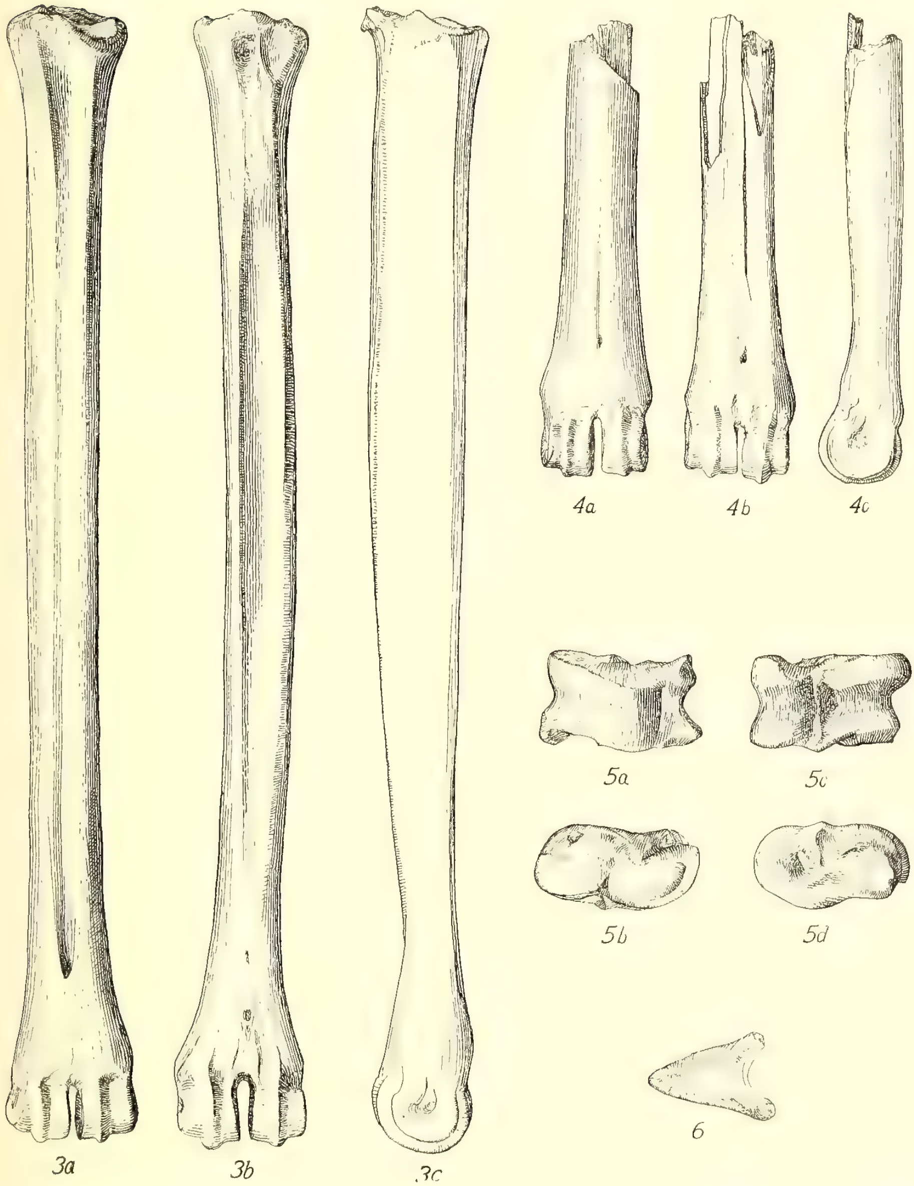
Metapodials.—The metapodials approach the antilocaprine type in the following characters. The anterior groove in the

posterior metapodial has approximately the same relative position as in the prong-horn, being slightly more median than is the case in the Cervidae. This groove is emphasized to about the same degree in *C.* (?) *minor* as in *Antilocapra americana,* being very shallow for the middle part of its length. The fossa external to the proximal end of the median anterior groove is pronounced, as in the prong-horn. The posterior median groove, while in general like that in *Antilocapra,* is wider. As in the prong-horn it becomes practically obsolete distally. In one specimen of the new form (no. 12516) the posterior groove, while deeper and considerably wider than it is in the *Antilocapra,* is very close to the latter form in the distal region.

Phalanges.—Two tiny toe-bones are in outline nearer to corresponding parts of *Ilingoceros* than to any other form of deer or antelope at hand. Their dorsal contour is slightly humped as in the twisted-horned antelope, but not nearly so much as in *Antilocapra.* The "Roman nose" effect, so evident in the latter, is consequently not so well developed. On the other hand, the dorsal contour is not straight as it is in *Odocoileus.*

Astragalus.—The ankle-bone shows certain minor differences when compared with corresponding parts of *Antilocapra americana* and *Ilingoceros alexandrae.* Viewed dorsally the little knob to the right of the central fossa, continuous with the inner surface of the right side of the trochlea, is not so much developed as in *Ilingoceros,* in which it in turn is not so prominent as in *Antilocapra.* The anterior fossa upon the right lateral aspect of the astragalus (fig. 5*b*) is slightly more extensive than in *Ilingoceros,* in which form the same fossa is a little more extensive than in *Antilocapra.* The posterior fossa is shallower in *Capromeryx* (?) *minor* than in either of the other forms mentioned, being nearer *Ilingoceros* in this respect.

Viewed upon its left side, the astragalus is nearer to *Ilingoceros.* On the dorso-proximal articular surface, seen from the left side, there is, as in the *Ilingoceros,* less of a groove than in *Antilocapra.* Furthermore, the rounded articular surface of this region does not swing around ventrally so far as in the prong-horn, resembling *Ilingoceros* also in this respect. The dorsal



Figs. 3*a* to 6.—*Capromeryx* (?) *minor*, new species. Rancho La Brea, near Los Angeles, California.

Figs. 3*a*, 3*b*, and 3*c*.—Posterior metapodial, no. 12516, natural size. Fig. 3*a*, anterior aspect; 3*b*, posterior aspect; 3*c*, lateral aspect.

Figs. 4*a*, 4*b*, and 4*c*.—Anterior metapodial, no. 10970, natural size. Fig. 4*a*, anterior aspect; 4*b*, posterior aspect; 4*c*, lateral aspect.

Figs. 5*a*, 5*b*, 5*c*, and 5*d*.—Astragalus, no. 12520, natural size. Fig. 5*a*, ventral aspect; 5*b*, right lateral aspect; 5*c*, dorsal aspect; 5*d*, left lateral aspect.

Fig. 6.—Lateral view of phalanx, no. 12521, natural size.

process in the center of the left lateral aspect (fig. 5*d*) is developed to a degree more nearly that of the prong-horn. The anterior fossa is nearer to *Ilingoceros.*

SUMMARY

The hypsodont teeth of the species represented by the material here discussed, as well as most of the characters of its metapodials, phalanges, and the astragalus, show that it should be placed with the antelopes.

The long-crowned teeth of *Capromeryx* (?) minor separate it from the true antelopes, even including the light-limbed African gazelles. The relatively long and light character of those limb-bones which have thus far been discovered is sufficient to separate the new species from most of the true antelopes (Antilopinae and Rupicaprinae). Its hypsodont teeth serve to separate it from the Tragulidae, the teeth of which are brachyodont.

Two facts indicate that the new species should not be referred to *Ilingoceros, Sphenophalos,* or *Neotragocerus*: first, the animal is smaller than those forms, and second, it occurs in deposits of a later geologic age. *Ilingoceros, Sphenophalos,* and *Neotragocerus* come from beds regarded as Lower Pliocene, the two first-named from Thousand Creek, Nevada, and the last-named from the *Neotragocerus* Zone of the Snake Creek deposits of western Nebraska. The composition of the Rancho La Brea fauna indicates that it is not earlier than Pleistocene.

Analogy with Recent artiodactyls such as *Cervus, Antilocapra, Odocoileus* as regards geographical range of individual species, together with probable minor variations from *Capromeryx furcifer* in size and tooth characters, lead to the conclusion that it is not referable to that species.

As regards Matthew's suggestion that *Capromeryx* is probably a descendent of the primitive deer-antelope group of which *Blastomeryx* and *Merycodus* are examples, the specialization indicated being substantially the same in direction as that exemplified by the prong-horn, it may be said that the characters of the new form support such a view.

If this form does belong to the genus *Capromeryx* an interesting tentative correlation is suggested between the fauna of the Rancho La Brea, and the plains fauna of the Hay Springs of the Niobrara River in western Nebraska. The age of the corresponding beds is probably approximately middle Pleistocene.

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TERTIARY MAMMAL BEDS
OF
VIRGIN VALLEY AND THOUSAND CREEK
IN
NORTHWESTERN NEVADA

BY
JOHN C. MERRIAM

PART II.—VERTEBRATE FAUNAS

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CONTENTS

INTRODUCTION

In a recent publication,[1] of which the present paper is considered as Part II, the writer has discussed the general features of the formations in the geologic section containing mammal-bearing beds in the region of Virgin Valley and Thousand Creek in northwestern Nevada. The present paper presents such evidence as is available regarding the vertebrate faunas obtained from the Virgin Valley and Thousand Creek formations. An attempt is also made to determine the approximate age of the faunas by use of both palaeontologic and geologic criteria of correlation.

A short list of the most characteristic forms in the fauna of Virgin Valley was published by Merriam[2] in 1907. In 1906 Gidley[3] discussed a number of the most characteristic ungulate species from the collections of the University of California. In 1910 Furlong[4] described a peculiar aplodont rodent from Virgin Valley, this form being the earliest known representative of the true aplodonts. In a recent paper Miss Louise Kellogg[5] has presented a description of the entire representation of the rodent group in the formations of Virgin Valley and Thousand Creek. Excepting the papers just mentioned, so far as the writer is aware, there are no published references to the vertebrate fauna of this region.

Although the collections from Virgin Valley and Thousand Creek furnish a most interesting representation of the mammalian fauna which inhabited these regions in late Tertiary time, the number of specimens obtained is relatively small compared

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[1] Merriam, J. C., Tertiary Mammal Beds of Virgin Valley and Thousand Creek in Northwestern Nevada, part I, Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 21-53, 1910.

[2] Merriam, J. C., Science, n.s., vol. 26, pp. 380-382, Sept. 20, 1907.

[3] Gidley, J. W., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 235-242, 1908.

[4] Furlong, E. L., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 397-403, 1910.

[5] Kellogg, Miss Louise, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 421–437, 1910.

with the collections which are commonly brought together in most of the series of mammal beds which have been investigated in this country. In Virgin Valley the number of localities where even fragments of bone are common is small. In the Thousand Creek Basin loose bones are quite abundant in many places.

In all of the exposures visited in this region the material consists almost entirely of scattered remains. Neither complete skeletons nor skulls could be obtained, though most careful search was made for them. Even when specimens were obtained in place in the rock they were found to consist entirely of isolated parts. There seems to be no question but that the bones were generally widely scattered, and usually in an advanced stage of disintegration before they were finally buried, which may be interpreted as a suggestion that the deposits represent in a large part dry land accumulations rather than those formed in lakes or swamps.

In the first publication of results of the work in the mammal-bearing beds of northwestern Nevada, the faunas of Virgin Valley and Thousand Creek were referred to collectively under the name of Virgin Valley fauna. More recent study has shown that the faunas of the formations at Virgin Valley and Thousand Creek are very different, and it is desirable to consider them separately before entering upon a discussion of their relative age.

After completion of the following paper it was the writer's privilege to compare the fauna here described with the most nearly related forms represented in other museums. For the free use of specimens desired for comparison, and for courtesies extended in the course of this examination, the writer is particularly indebted to Mr. J. W. Gidley and Mr. C. W. Gilmore of the National Museum; to Professor Henry F. Osborn, Dr. W. D. Matthew, and Mr. Walter Granger, of the American Museum of Natural History; and to Dr. W. J. Holland of the Carnegie Museum.

All of the drawings used in illustration of this paper were prepared by Mrs. Louise Nash.

FAUNA OF THE VIRGIN VALLEY BEDS

Occurrence and Composition.—The section exposed in Virgin Valley has been more or less arbitrarily subdivided as follows:

Upper Zone.	White to buff beds. Ashes and diatomaceous beds.	Upper Virgin Valley?
		Unconformity?[6]
Middle Zone.	Gray to yellow and brown shales and clays. Carbonaceous shales, lignites, diatomaceous beds.	Lower Virgin Valley?
Lower Zone.	White to green, purple, and red clays and ashes.	

The zones as indicated above are not sharply defined, but where the attempt has been made to trace them they seem to be fairly persistent. Careful mapping of these horizons throughout the valley is desirable.

No mammalian remains have been found in Virgin Valley in characteristic beds of the lower zone, and only imperfect fragments were found in that portion of the section above the horizon at which an unconformity appears between the rhyolitic gravels and the underlying fine-grained beds.

Locality 1065, on the south side of the valley of Virgin Creek, the original locality at which mammalian fossils were found by McGhee, is immediately below the carbonaceous shales of the middle division; while locality 1091 on the west side of Beet Creek is a considerable distance above the carbonaceous shales. Most of the other localities at which collections have been made in Virgin Valley would probably fall within the limits of vertical range marked by these two localities. Mapping of the faunal and lithologic zones of the Virgin Valley Beds will probably show that the principal fossil horizons fall within a zone only a few hundred feet in thickness situated near the middle of the section. Other fossiliferous beds are naturally to be expected both above and below this horizon.

The complete list of mammalian species obtained from all of the localities in the Virgin Valley Beds is as follows:

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[6] Merriam, J. C., *op. cit.*, part I, pp. 36, 43, and pl. 8.

Fauna of Virgin Valley Beds

Reptilia.
- *Clemmys,* sp.

Carnivora.
- *Tephrocyon kelloggi,* n. sp.
- *Tephrocyon* (?), compare *rurestris* (Condon).
- *Tephrocyon* (?), sp. *a.*
- *Aelurodon* (?), sp.
- *Probassariscus antiquus matthewi,* n. gen. & n. var.
- *Felis,* sp. ?

Rodentia.
- *Aplodontia alexandrae* Furlong.
- *Mylagaulus monodon* Cope.
- *Mylagaulus pristinus* Douglass.
- *Palaeolagus nevadensis* Kellogg.
- *Lepus vetus* Kellogg.

Ungulata.
- *Hypohippus,* near *osborni* Gidley.
- *Parahippus,* compare *avus* (Marsh).
- *Merychippus isonesus* (Cope).
- *Aphelops* (?), sp.
- *Moropus* (?), sp.
- Mastodon (*Tetrabelodon* ?, sp.).
- *Merychyus* (?), sp.
- Camel, near *Procamelus.*
- *Thinohyus* (?), sp.
- *Blastomeryx mollis,* n. sp.
- *Dromomeryx* (?), sp. *a*, near *borealis* (Cope).
- *Dromomeryx,* sp. *b.*
- *Merycodus,* near *furcatus* (Leidy).
- *Merycodus nevadensis,* n. sp.

The largest collection brought together at any one locality is that from the exposure discovered by McGhee, which probably represents the lowest horizon from which any considerable amount of material was collected. The following forms were obtained at this locality:

Lowest Mammal Beds in Virgin Valley, Locality 1065

- *Tephrocyon kelloggi,* n. sp.
- *Mylagaulus monodon* Douglass.
- *Palaeolagus nevadensis* Kellogg.
- *Lepus vetus* Kellogg.
- *Hypohippus,* near *osborni* Gidley.
- *Merychippus isonesus* (Cope).
- *Aphelops* (?), sp.

Moropus (?), sp.
Blastomeryx mollis, n. sp.
Dromomeryx, sp. *a,* near *borealis* (Cope).
Merycodus, near *furcatus* (Leidy).
Mastodon (*Tetrabelodon* ?, sp.).
Camel, near *Procamelus.*

Nearly all of the species from this locality are found also at other places and presumably at other horizons. The only form not known elsewhere is *Palaeolagus,* represented by a single specimen. The relative abundance of material at this place would make probable the discovery here of some of the rarer forms. At other localities considered as higher in the section than no. 1065 the species are largely the same as at this horizon. With these are a few rare forms, as *Merychyus* and *Thinohyus* (?), known by only one or two specimens, and representing groups typical of horizons much older than the lowest Virgin Valley beds are presumed to be, so that there is reason to believe that they were present during the deposition of the lowest mammal-bearing beds, but are sufficiently rare to have escaped observation in collecting this far. The only other important forms not known in the lowest horizon are *Aplodontia* and *Probassariscus,* each known by a single specimen. The specimen of *Aplodontia* is doubtfully higher in the section than the beds at locality 1065. *Probassariscus* was presumably a little higher.

From the above statement it appears that the fauna of the various localities in Virgin Valley is practically a unit, and may be considered collectively in any attempt at correlation.

Faunal Relationships.—The closest relationship of the Virgin Valley fauna seems to be with that of the Mascall Beds of Oregon and of the Pawnee Creek Beds of Colorado. The Snake Creek Beds of Nebraska contain a larger percentage of the Virgin Valley species than either the Mascall or Pawnee Creek, but there seems, nevertheless, good reason for considering the relationship with the other faunas as closer.

The ungulate fauna of Virgin Valley fauna resembles that of the Mascall in the presence of *Hypohippus, Parahippus, Merychippus,* and *Dromomeryx;* and in the persistence of at least one oreodont (*Merychyus?*). The brachyodont horse *Hypohippus*

has not been known from the typical locality of the Mascall, but has recently been noted by the writer in Mascall collections from the Crooked River region, south of the Blue Mountains in Oregon. At the type locality of the Mascall one other horse with short-crowned cheek-teeth (*Archaeohippus*) is represented. *Merychippus* is the most common horse in both the Virgin Valley and the Mascall, and *Pliohippus* is apparently absent from both faunas. The *Pliohippus* specimens reported from the Mascall are doubtful. *Tephrocyon*, the most characteristic carnivore of Virgin Valley, and *Mylagaulus*, the most characteristic rodent, are both included in the Mascall fauna.

With Pawnee Creek the Virgin Valley ungulate fauna has a large percentage of forms in common. In both faunas *Hypohippus, Parahippus,* and *Merychippus* are present without accompanying *Pliohippus*. The genera *Moropus, Merychyus, Blastomeryx* and *Merycodus* appear in both, while the rhinoceroses, mastodons and camels are suspiciously similar. *Mylagaulus* appears in both faunas, and some of the Pawnee Creek canids are doubtfully referred to *Tephrocyon*.

The fauna of the Snake Creek Beds of western Nebraska shows a remarkable similarity to that of Virgin Valley, a larger percentage of Virgin Valley species being found in the Snake Creek fauna than in any other assemblage of forms known to the writer. Particularly noticeable is the practical identity of several of the carnivore forms as *Tephrocyon, Felis,* and *Probassariscus*. The Virgin Valley *Probassariscus* differs from that of Snake Creek so slightly that the distinction may not be considered as of more than subspecific value. The deer-like forms *Dromomeryx, Blastomeryx,* and *Merycodus* appear in both faunas. Among the horses *Hypohippus, Parahippus,* and *Merychippus* are common to the two, but the abundance of more advanced forms of the *Neohipparion* and *Protohippus* types indicate that the Snake Creek fauna must represent a stage considerably later than that of Virgin Valley. The difference between the two faunas presumably corresponds to a time interval about as long as that represented by the Upper Miocene, but is probably not longer than that division.

Determined according to the range of mammalian genera in North America, the Virgin Valley fauna must be considered as Middle Miocene. The generic types represented are those commonly found in the middle and upper divisions of the Miocene. The Lower Miocene is excluded by the advanced stage of development of the horses represented in *Hypohippus* and *Merychippus*, the extreme rarity of oreodonts, and the presence of advanced deer-like forms such as *Dromomeryx* and *Merycodus*. The presence of *Moropus* with a Thinohyus-like form and the absence of *Pliohippus* indicate a stage earlier than Upper Miocene. About equal numbers of upper and lower Miocene genera are present, but the Middle Miocene character of the fauna is indicated by the abundance of *Hypohippus* and *Merychippus* with the entire exclusion of any forms of the *Pliohippus* or *Protohippus* type.

Relation of Virgin Valley Fauna to its Environment.—The greater part of the mammalian material from Virgin Valley was obtained in the zone which includes the carbonaceous shales and lignite deposits. In this zone diatomaceous deposits are well developed, and fragmentary fish remains are occasionally found. Fossil wood of large conifer-like trees is abundant at many localities in this portion of the section. The nature of the deposit in general indicates that moist ground, swamps, and possibly even considerable bodies of water existed in this region during the period in which the typical Virgin Valley fauna flourished. Concerning the nature of the vegetation we know as yet comparatively little, as most of the remains obtained were imperfectly preserved. The plant specimens from the carbonaceous shales include rushes, willows, and a number of other forms not determined.

The nature of the deposits and of the contained remains in the principal mammal-bearing zone of the Virgin Valley Beds does not necessarily indicate that conditions were then entirely different from those obtaining in this region at the present time. Large marshy areas and lakes of considerable size existing today in the northern Basin region are the habitat of abundant plant and animal life, while the most arid conditions may obtain only a few hundred yards from the water. Considering, however, the

general persistence of moist conditions, and the nature of the vegetation indicated in this section, the weight of evidence indicates that the climate was more humid and somewhat warmer than at present. The vegetation suggests also that the altitude was probably less than 5000 feet, which is now approximately the level of the mammal zone in Virgin Valley.

As nearly as can be judged from our present knowledge, the Virgin Valley Beds were laid down over a region in which faulting had already produced a certain degree of relief. As the deposition progressed, the irregularities of topography were gradually smoothed over by filling in of the depressions, until plains or shallow lakes of wide extent had been developed.

The nature of the mammalian fauna occupying the Virgin Valley region in Middle Miocene time accords well with what one might expect in such an environment. *Probassariscus* among the carnivores, *Aplodontia* of the rodents, and the brachyodont *Hypohippus* of the ungulates suggest a region containing wooded areas. *Merychippus* and *Merycodus,* with long-crowned grazing teeth, suggest the open plains. As nearly as we can determine, both kinds of environment were available, and in localities so near together that remains representing the two types of faunas might readily be mingled in accumulations forming over the lowest areas of the region.

FAUNA OF HIGH ROCK CANON AND LITTLE HIGH ROCK CANON

The exposures at High Rock Cañon and Little High Rock Cañon resemble those of Virgin Valley in many respects. The collections made at these localities comprise the following forms:

High Rock Cañon	Little High Rock Cañon
Tephrocyon (?), compare *rurestris* (Condon).	*Moropus* (?), sp.
Tephrocyon (?), sp. *a.*	
Aelurodon (?), sp.	
Merychippus isonesus (Cope).	
Merychippus, near *seversus* (Cope).	
Aphelops (?), sp.	
Moropus (?), sp.	
Mastodon (*Tetrabelodon* ?, sp.).	
Blastomeryx mollis, n. sp.	
Merycodus nevadensis, n. sp.	

The affinities of this fauna with that known from Virgin Valley are close enough to indicate that the beds near High Rock Cañon probably represent the same epoch as the mammal beds of Virgin Valley.

FAUNA OF THE THOUSAND CREEK BEDS

Occurrence and Composition.—The beds at Thousand Creek stretch over a territory many miles in extent, but the sections examined thus far are not more than a few hundred feet in thickness. The basal strata have not been seen in these exposures. As these beds seem to extend a considerable distance to the north beyond the farthest point thus far examined, it is possible that still lower horizons may yet be found.

The nature of the formation does not vary greatly throughout the region as a whole, and the strata are generally horizontal or only slightly inclined. There are a few well-marked beds which with careful work might be traced and mapped for a considerable distance. A sharply defined stratum of white to gray ash in the northern part of the basin resembles an ash layer at the southern end of the field so closely as to suggest their representing the same horizon.

Around the border of the Thousand Creek Flats there are several terraces evidently formed in late Pleistocene time. The possibility of Pleistocene deposits occurring on these terraces and being confused with an older formation was considered in the field. With the exception of one or two cases, which are especially considered under the discussion of the fauna, the exposures in which collections were obtained could not be separated from the pre-Pleistocene formation here referred to as the Thousand Creek Beds.

Mammalian fossils have been found in most of the exposures in this region, though they are comparatively rare at some places. A complete list of the species from the localities about the Thousand Creek Basin is as follows:

FAUNA OF THOUSAND CREEK BEDS

Reptilia.
Ophidian remains.

Aves.
Branta, sp.

Insectivora.
Scapanus (?), sp.

Carnivora.
Tephrocyon, near *kelloggi*, n. sp.
Canis (?) *davisi*, n. sp.
Ursus (?), sp.
Mustela furlongi, n. sp.
Mustelid, indet.
Felis, sp. *a*.
Felis, sp. *b*.

Rodentia.
Arctomys nevadensis Kellogg.
Arctomys minor Kellogg.
Citellus, sp.
Aplodontia alexandrae Furlong.
Mylagaulus monodon Cope.
Dipoides, sp.
Eucastor lecontei (Merriam) ?.
Entoptychus minimus Kellogg.
Peromyscus antiquus Kellogg.
Peromyscus (?), sp.
Diprionomys parvus Kellogg.
Diprionomys magnus Kellogg.
Lepus vetus Kellogg.

Ungulata.
Pliohippus (?), sp.
Equus (?), sp.
Teleoceras (?), sp.
Mastodon (*Tetrabelodon* ?, sp.)
Pliauchenia (?), sp.
Camel, compare *Camelus americanus* Wortman.
Prosthennops (?), sp.
Large suilline form.
Sphenophalos nevadanus Merriam.
Ilingoceros alexandrae Merriam.
Ilingoceros schizoceras, n. sp.

In the collections made in this region thus far no evidence has appeared which indicates definitely a distinct zonal arrange-

ment of the fauna. There are differences between the faunas of some of the localities, but the vertical difference in position of these beds is not great, and the variation may be due to factors other than vertical range.

While the work of collecting was in progress, the question frequently arose as to whether any of the mammalian remains obtained at Thousand Creek were derived from Pleistocene deposits. As has been stated above, in those cases where the deposits could be examined, there seemed good reason for considering them as all belonging to one formation, while the palaeontologic evidence indicates that this formation is older than Pleistocene. At one or two localities where loose bones were collected on the broad terraces north of the mouth of Thousand Creek, and along the southwestern border of Thousand Creek Basin, remains of horses were obtained which are not distinctly separable from the genus *Equus*. The presence of remains referred to *Equus* has suggested that these particular specimens may be derived from Pleistocene deposits resting upon the older beds. Similar remains are, however, found at other localities where the suggestion of Pleistocene age is not so strong. There does not as yet seem to be reason for considering that two faunas are mingled in these deposits. If such mingling occurs the amount of material derived from deposits younger than the Thousand Creek Beds must be very small.

The collections obtained from localities 1096, 1097, 1100, and 1101 are not widely separated geographically, and are from nearly the same horizon, so that they may be taken as a fair representation of the fauna of the Thousand Creek Beds. The species from these localites include the following forms:

THOUSAND CREEK FAUNA, LOCALITIES 1096, 1097, 1100, 1101.

Branta, sp.
Canis (?) *davisi*, n. sp.
Ursus (?), sp.
Felis, sp. *a*.
Lepus vetus Kellogg.
Pliohippus (?), sp.
Equus (?), sp.
Teleoceras (?), sp.

Mastodon (*Tetrabelodon* ?, sp.)
Camel, compare *Camelus americanus* Wortman.
Large suilline form.
Sphenophalos nevadanus Merriam.
Ilingoceros alexandrae Merriam.
Ilingoceros schizoceras, sp.

A number of species of carnivores and rodents not known from the localities mentioned above were obtained at locality 1103, at approximately the same level as these localities and less than two miles away, on the west side of Railroad Ridge. This collection contained the following species:

Ophidian remains.
Scapanus (?), sp.
Tephrocyon, near *kelloggi*, n. sp.
Mustela furlongi, n. sp.
Mustelid, indet.
Arctomys minor Kellogg.
Citellus, sp.
Aplodontia alexandrae Furlong
Dipoides, sp.
Entoptychus minimus Kellogg
Peromyscus antiquus Kellogg.
Peromyscus (?), sp.
Diprionomys parvus Kellogg.
Diprionomys magnus Kellogg.

Although this collection contains no species corresponding to those from the four localities mentioned above, it is noted that the forms present represent an entirely different faunal phase. The genera included in the list from locality 1103 are in some cases types known in the Virgin Valley Beds, as *Tephrocyon* and *Aplodontia*, while others as *Citellus*, *Arctomys*, and *Peromyscus* have a more recent aspect. Considering that there is no reason for presuming this collection to represent an intimate mixture of specimens derived from more than one formation, this phase of the fauna seems to represent approximately the same stage of evolution as that in the list from the first four localities mentioned.

Other genera not found at the four localities first named are *Mylagaulus* and *Prosthennops* (?), found high up in the series at locality 1098.

Relation to Virgin Valley Fauna

Comparative Table of Faunas of Virgin Valley and Thousand Creek

VIRGIN VALLEY BEDS	THOUSAND CREEK BEDS
Reptilia.	Reptilia.
Clemmys, sp.	Ophidian remains.
	Insectivora.
	Scapanus(?), sp.
Carnivora.	Carnivora.
Tephrocyon kelloggi, n. sp.	*Tephrocyon*, near *kelloggi*, n. sp.
Tephrocyon(?), compare *rurestris* (Condon).	*Canis*(?) *davisi*, n. sp.
Tephrocyon, sp. *a*.	*Ursus*(?), sp.
Aelurodon(?), sp.	*Mustela furlongi*, n. sp.
Probassariscus antiquus matthewi, n. gen. & n. var.	Mustelid(?), indet.
Felis, sp. *a* (?).	*Felis*, sp. *a*.
	Felis, sp. *b*.
Rodentia.	Rodentia.
Aplodontia alexandrae Furlong.	*Arctomys nevadensis* Kellogg.
Mylagaulus monodon Cope.	*Arctomys minor* Kellogg.
Mylagaulus pristinus Douglass.	*Citellus*, sp.
Palaeolagus nevadensis Kellogg.	*Aplodontia alexandrae* Furlong.
Lepus vetus Kellogg.	*Mylagaulus monodon* Cope.
	Dipoides, sp.
	Eucastor lecontei (Merriam)?.
	Entoptychus minimus Kellogg.
	Peromyscus antiquus Kellogg.
	Peromyscus(?), sp.
	Diprionomys parvus Kellogg.
	Diprionomys magnus Kellogg.
	Lepus vetus Kellogg.
Ungulata.	Ungulata.
Hypohippus, near *osborni* Gidley.	*Pliohippus*(?), sp.
Parahippus, compare *avus* (Marsh).	*Equus*(?), sp.
Merychippus isonesus (Cope).	*Teleoceras*(?), sp.
Aphelops(?), sp.	Mastodon (*Tetrabelodon* ?, sp.)
Moropus(?), sp.	*Pliauchenia*(?), sp.
Mastodon (*Tetrabelodon* ?, sp.)	Camel, compare *Camelus americanus* Wortman.
Merychyus(?), sp.	*Prosthennops*(?), sp.
Camel, near *Procamelus*.	*Sphenophalos nevadanus* Merriam.
Thinohyus(?), sp.	*Ilingoceros alexandrae*, Merriam.
Blastomeryx mollis, n. sp.	*Ilingoceros schizoceras*, n. sp.
Dromomeryx, sp. *a*, near *borealis* (Cope).	
Dromomeryx, sp. *b*.	
Merycodus, near *furcatus* (Leidy).	
Merycodus nevadensis, n. sp.	

From the lists available, it is evident that the faunas of Virgin Valley and Thousand Creek represent distinct epochs in the evolution of the mammalia of western North America. Between the times of the deposition of the two series of deposits sweeping changes in the fauna of this region had taken place. The only species known to persist from Virgin Valley to Thousand Creek time are three rodents; two of which, *Aplodontia* and *Lepus*, represent extraordinarily persistent genera. The third form, *Mylagaulus*, has a range from Middle Miocene to Pliocene. The single M_2 of *Tephrocyon* found at locality 1103 does not differ markedly from the corresponding tooth of *T. kelloggi* from Virgin Valley. Other than these species there are no forms which appear to be common to the two series of beds. The mastodon, a large cat, and perhaps some of the camels, may be similar in the two formations, but the material available is not sufficient for specific comparison.

The possible elements common to the Thousand Creek and Virgin Valley Beds are the following, of which the last three are very doubtful and the fourth uncertain.

Aplodontia alexandrae Furlong.
Mylagaulus monodon Cope.
Lepus vetus Kellogg.
Tephrocyon, near *kelloggi*, n. sp.
Felis, sp. *a* (?)
Mastodon (*Tetrabelodon* ?, sp.)
Camelid(?)

The ungulates may presumably be fairly taken as a basis for comparison of the two faunas, inasmuch as they include a large percentage of the species known, and are, moreover, the most abundantly represented among the specimens collected in the two regions. In this group we find *Hypohippus, Parahippus, Merychippus, Moropus, Merychyus, Dromomeryx, Blastomeryx*, and *Merycodus* of the Virgin Valley fauna entirely unrepresented in the Thousand Creek Beds. At Thousand Creek horses of the *Pliohippus* type are the common forms; the only other remains of this group known are the few tentatively referred to *Equus*. Among the artiodactyls a small dicotyline from Thou-

sand Creek seems to be generically different from the only remains found in Virgin Valley referable to the Suidae in the wider sense. The large camels, which are among the most common fossils at Thousand Creek, seem not to be represented at Virgin Valley. *Ilingoceros,* the peculiar twisted-horned antelope of Thousand Creek, and *Sphenophalos,* the Antilocapra-like form occurring with it, have not been discovered in any of the Virgin Valley collections.

The difference between the faunas of Virgin Valley and Thousand Creek is so wide that a very considerable period must have elapsed between the times of deposition of these two sets of beds. It seems scarcely possible that the changes here indicated could be quantitatively less than those which took place between the Middle Miocene and the Pliocene of well-known regions, or that the time period represented could be less than that occupied by the Upper Miocene stage of evolution of the mammalia.

General Relationships of Thousand Creek Fauna.—Among the various assemblages of mammalian forms known in America the fauna of Thousand Creek is unique. Its closest relationships are apparently with Pliocene faunas as represented by the mammalia of the Snake Creek and Blanco, but to neither of these does it correspond closely.

As has already appeared, only a limited number of the Thousand Creek generic types, and a smaller number of the species occur in the Middle Miocene fauna of Virgin Valley, while the presence of such ancient genera as *Tephrocyon, Mylagaulus,* and *Teleoceras* excludes the possibility of referring the Thousand Creek fauna to a period as late as even the earliest Pleistocene.

The number of Thousand Creek species appearing in the Snake Creek fauna is slightly larger than that found in any other known assemblage of mammalian forms in America. The list of forms common to the two includes the types *Tephrocyon, Mustela, Felis, Mylagaulus, Dipoides, Pliohippus,* and presumably *Teleoceras.* The camels and mastodons are also not improbably closely related. These two faunas are the only ones in

America known to include antelopes suggesting close relationship with the typical Old World forms. In spite of a partial resemblance, the Thousand Creek fauna differs distinctly from that of Snake Creek in the absence of all representatives of *Hypohippus, Parahippus, Merychippus, Merychyus, Blastomeryx*, and *Merycodus,* the horses being represented by *Pliohippus,* possibly accompanied by *Equus*, and the booid artiodactyls by previously unknown types of antelopes. There seems no question but that the Thousand Creek fauna is younger than that of Snake Creek, though evidently as near to the Snake Creek stage as to any other recognized horizon in America.

The Blanco Pliocene fauna of Texas resembles that of Thousand Creek in the absence of horses below the stage of *Protohippus* and *Neohipparion.* Unfortunately the Thousand Creek camels and mastodons are not well enough known for a thoroughly satisfactory comparison. In the disappearance of rhinoceroses, mylagaulids and tephrocyons, and in the appearance of several southern types of edentates the Blanco stage is more advanced than that of Thousand Creek.

In so far as correlation with the American mammalian faunas is concerned the Thousand Creek fauna would seem necessarily to take a place later than that of the Snake Creek and earlier than that of the Blanco. With this arrangement it seems probable that the Snake Creek fauna can hardly be considered as later than early Lower Pliocene, verging on the Miocene. The Thousand Creek fauna may be included in the lower Pliocene, but must represent a late stage of this division. The Blanco fauna is presumably considerably later than that of Thousand Creek. Though the variation may be due in part to geographic and climatic differences, it is hardly probable that if the Thousand Creek fauna represents the late Lower Pliocene the Blanco can represent a horizon as early as the earliest Middle Pliocene.

RELATIVE AGE OF VIRGIN VALLEY AND THOUSAND CREEK FAUNAS, ACCORDING TO GENERAL CORRESPONDENCE AND STAGE OF EVOLUTION

Middle Pliocene		Blanco
Lower Pliocene	Thousand Creek	Snake Creek
Upper Miocene		Santa Fe and Madison Valley
Middle Miocene	Virgin Valley	Mascall, Deep River, and Pawnee Creek

Relation of Thousand Creek Fauna to its Environment.—The deposits formed during the Thousand Creek epoch are not characterized by lignitic beds or carbonaceous shales as in the Virgin Valley section, nor have water-laid deposits containing abundant plant remains been recognized. The deposits do, however, contain scattered bones of small fishes in at least one locality examined, and were evidently in some part formed in standing water. Some of the material is volcanic ash which accumulated rapidly. Another portion is made up of beds which resemble soil accumulations, to which additions may have been made by dust or fine ash deposits.

From the character of the Thousand Creek Beds taken by themselves there is little to indicate the nature of the climatic conditions that obtained in this region while they were being deposited. So far as the evidence at hand may be interpreted, there seems no reason for presuming that the conditions at that time differed far from the possible range of environment within the Basin region at the present time. The degree of humidity may have been slightly higher than to-day, but the evidence favoring this view is derived mainly from the character of the fauna. Presumption is in favor of the view that the degree of humidity was less than during the deposition of the principal mammal beds in Virgin Valley.

The distribution and stratigraphic relations of the Thousand

Creek Beds so far as known suggest that the topography of the region in this epoch resembled an advanced stage in the evolution of the topography begun in Virgin Valley time. Considerably elevated regions still existed, but around these the deposits had been built up till many of the minor irregularities had been completely buried, and a much wider expanse of level country was presented. According to any interpretation which may be put upon the depositional history of this region we must consider that the extent of plains territory here during Thousand Creek time was approximately as great as that of the wide stretches of level land in the great valleys of the Basin region at the present time.

In the mammalian fauna, the ungulates of the Thousand Creek Beds represent in general types somewhat better adapted to a plains region than was the fauna of the Virgin Valley epoch. The only horses present are *Pliohippus,* and possibly *Equus,* with well-developed prismatic crowns of the molar teeth, while the only booid artiodactyls are antelopes with long-crowned molars.

That the fauna of the region was not limited entirely to open and semi-arid plains is suggested by the presence of a goose (*Branta*), a mole (*Scapanus*), and a possible representative of *Ursus.* Among the rodents the sewell (*Aplodontia*) was presumably a dweller in a moist region with abundant vegetation. *Arctomys* is not a characteristic plains form, but might have lived on the borders of open country.

The mammalian fauna as a whole suggests plains with occasional lakes or meadows bordering rugged or elevated areas. The degree of humidity may have been somewhat greater, and vegetation more abundant than at the present time. The presence of *Arctomys* may suggest a slight cooling of the climate, either due to general climatic changes, or to elevation of this region.

GENERAL CORRELATION OF VIRGIN VALLEY AND THOUSAND CREEK BEDS ON THE BASIS OF PHYSICAL AND FAUNAL RELATIONSHIPS TO OTHER FORMATIONS OF THE PACIFIC COAST REGION

Such reference to correlation of the formations of northern Nevada as has appeared in this discussion up to the present time has been based upon either stratigraphic or faunal evidence considered alone. It seems important to consider the relation of these formations to each other, and to other members of the Tertiary system in the Pacific Coast region in the light of the combined evidence from these fields of investigation, in order to see the fragments of the palaeontologic record placed as nearly as possible in their true relative positions. In farther discussion it is desirable to use all of the available means of comparison checked against each other, in the hope that thus combined they may ultimately accomplish more than has been possible with any one group alone.

Relation of Virgin Valley and Thousand Creek Beds to each other.—In the discussion of the geologic relations of the Thousand Creek Beds, in Part I of this paper[7] the writer has indicated the difficulties in the way of determining the exact geologic relations of the Virgin Valley and Thousand Creek formations to each other without farther study of this region. An investigation of the territory to the north and east would probably furnish the information necessary to make clear the doubtful factors in the physical history.

The palaeontologic relations of the two formations seem pretty clearly defined. While the writer has constantly held in mind the possibility that a mixture of Miocene and Pleistocene species might result in a determination of the age of the Thousand Creek Beds as Pliocene, the evidence before us does not seem to indicate that this is the case. A Miocene fauna such as that of Virgin Valley does not seem to be represented in the

[7] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 45–50, 1910.

Thousand Creek collections, though a few of the Virgin Valley species are present. In the horse group the presence of *Pliohippus* and the absence of the Virgin Valley *Hypohippus, Parahippus,* and *Merychippus* seem to exclude the Middle Miocene, the Pleistocene, and probably also the Upper Miocene. Among the booid artiodactyls, the presence of the peculiar antelope forms *Ilingoceros* and *Sphenophalos,* not known in the Virgin Valley Beds, and unknown in the abundantly represented Pleistocene faunas of the Pacific Coast region, together with the absence of *Dromomeryx, Blastomeryx,* and *Merycodus,* again indicates that the Thousand Creek Beds represent a stage distinctly later than the Middle Miocene and earlier than Pleistocene.

The physiographic history of the Thousand Creek region as indicated in the terrace levels bordering the valley, leads one to suspect that Pleistocene deposits might be present, and that mammalian remains derived from them could be mingled with those from the underlying Pliocene beds. As has been indicated in the preceding discussions, no definite suggestion as to such mingling has been offered, excepting in the case of a few specimens, especially certain remains of an Equus-like form obtained from some of the terraces. The same form occurs, however, at another locality where rhinoceros remains seemed to be present with it.

It will not be surprising if future observations show that a Pleistocene fauna is represented at Thousand Creek. With the evidence at hand it does not appear that the question as to the age of the extensive exposures recognized as the Thousand Creek Beds, and containing a fauna including *Protohippus,* and rhinoceroses is seriously complicated by such remains as are doubtfully Pleistocene.

As was indicated in the discussion of the physical history of the Virgin Valley and Thousand Creek region in Part I of this paper the possibilities as to age of the Thousand Creek Beds with relation to the Virgin Valley Beds appear to be as follows. The Thousand Creek Beds may be:

(1) Upper Virgin Valley Beds, faulted down.

(2) Post-Virgin Valley and pre-Mesa-Basalt, faulted down.

(3) Post-Mesa-Basalt; formed from older wash of Virgin Valley, faulted down.

(4) Post-Mesa-Basalt; formed from younger wash of Virgin Valley, not moved far by faulting.

(5) Composite, partly Virgin Valley and partly Pleistocene.

When checked by what we know of the faunal relationships of the Virgin Valley and Thousand Creek Beds, it is noted that the interval between the Virgin Valley and Thousand Creek faunas seems to amount to a period at least as long as the Upper Miocene, and that the Thousand Creek Beds cannot be later than early Pliocene. This would make it improbable that the Thousand Creek Beds belong to the same period of deposition as the Virgin Valley. On the other hand it seems improbable that the cutting of the present cañon of Thousand Creek was well under way before the beginning of Pliocene time. These suggestions seem to narrow the problem down to the following possibilities:

(1) That the Mesa Basalt is Miocene in age and that the present cañons began to cut in early Pliocene time, the Thousand Creek Beds being formed by the accumulations of early wash from this erosion.

(2) That the Thousand Creek Beds represent a pre-Mesa Basalt formation of considerably later age than the principal mammal zone of the Virgin Valley Beds.

According to the first view the Thousand Creek Beds are post-Mesa-Basalt in age, and were accumulated during the cutting of Virgin Valley or other valleys of approximately the same age. There are several arguments which may be put forward in support of this view, but it seems especially desirable to have more evidence regarding the relation of the northern and western extensions of the Thousand Creek Beds to the Mesa Basalt before it can be seriously considered.

The second view postulates the pre-Mesa-Basalt age of the Thousand Creek Beds and makes them either the equivalent of the uppermost portion of the Virgin Valley section or a pre-Mesa-Basalt accumulation formed from the erosion of the Virgin Valley and not represented in the portion of the Virgin Valley section examined. The fact that the upper portion of the Virgin

Valley section seems to be separated from the middle zone by an unconformity below the rhyolitic gravels lends some support to this view. If, as seems to be the case, the unconformity below the rhyolitic gravels in Virgin Valley is not due to accumulation during the cutting of the present valley; and if this unconformity is not a purely local discordance due to extraordinary stream action in Virgin Valley time, then there is reason to consider the Virgin Valley as divisible into two periods of sedimentation which may have been separated by a considerable epoch of erosion.

The Thousand Creek Beds may correspond to that portion of the Virgin Valley series above the unconformity. Also if the unconformity should appear to be between typical Virgin Valley Beds and gravels laid down in the course of the cutting of the valley, the gravels may correspond to some phase of the Thousand Creek Beds. So far as these possibilities are concerned, it is important to know if a fauna similar to that of Thousand Creek can be obtained in the uppermost portion of the section of Virgin Valley. As yet nothing characteristic of either the Virgin Valley or the Thousand Creek faunal phase has been obtained from this portion of the section. The only suggestion of evidence has come through the examination of a number of the low hills in Virgin Valley which seem to be formed by slides which have come down from the summit of the mesa. In this locality mastodon remains seem more abundant than in other places in Virgin Valley, and the only specimen representing a very large feline was found here. At Thousand Creek, mastodon remains are more abundant than at Virgin Valley, and remains of very large felines are well known.

In order to come to an entirely clear understanding of the true stratigraphic relations of the Virgin Valley and Thousand Creek beds it will be necessary to make a farther examination of the geology of this region. Such evidence as will make perfectly clear the relation of the biologic succession to the series of events in the physical history of this region is much to be desired, as the final understanding of either the biological or the physical history of the Pacific Coast region can be accomplished only by utilizing all evidence which can be obtained. A

clear understanding of the relation of the physical and biologic successions to each other will often make possible the bringing together in intelligible form of evidence otherwise entirely without meaning.

Relation of Virgin Valley Beds to the Middle Miocene Formations of the Pacific Coast and Basin Regions.—As has been set forth in Part I of the present paper,[8] the Virgin Valley Beds rest upon a floor of older igneous rocks, which apparently correspond to the upper portion of a great series of basalts and rhyolites to which the tentative name of Pueblo Range Series has been applied. This igneous series has been traced to the north by Waring,[9] and is considered by him to represent a southward extension of the great lava flows along the Columbia River. The complete section from southern Oregon to the typical region of the Columbia Lava has not been actually traced, and it is most desirable that the connection should be carefully worked out. There are, nevertheless, strong reasons for considering with Blake and Waring that the eruptive series of southern Oregon is only a part of the series of flows which cover such an enormous extent of territory farther to the north, and certain suggestions as to broader correlations may tentatively be based upon this supposition.

It is well worth noting that the relation of the Virgin Valley Beds to the older rocks referred to the Pueblo Range Series as determined on purely physical evidence is approximately the same as the relation of the Mascall Beds of the John Day region to the Columbia Lava; while on the basis of the similarity of mammalian faunas the Mascall and Virgin Valley are considered as representing the same epoch, viz., the Middle Miocene. The biological and physical relations considered together seem to indicate pretty clearly that we are dealing with the same stratigraphic sequence in the two regions.

The relation between the Columbia Lava and the Middle Miocene sedimentary formations containing a characteristic mammalian fauna seems to be one of unusual importance for

[8] Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 26-30, 1910.

[9] Waring, G. A., U. S. Geol. Surv. Water Supply, 231, p. 2, 1909.

correlation purposes. In no other region, and at no other geologic horizon, do we know a series of igneous outflows exceeding in magnitude and in areal extent the Miocene lavas in and contiguous to the Columbia River area. For purposes of reference in correlation this series would seem to furnish a most important datum plane wherever it can be traced, or wherever recognized by any petrographic peculiarities.

Following the deposition of the early Miocene lava flows, conditions favorable for the accumulation of sediment obtained in many areas over the lava-covered regions, and extensive deposits were formed, of which presumably a large part have since disappeared through erosion; but patches and even extensive areas have remained in many places. During this period the rich and varied mammalian fauna would presumably distribute itself with unusual uniformity over the wide stretch of territory which had been occupied in the period immediately preceding by the great lava flows. It is to be presumed that the large lava areas, covering more than 250,000 square miles, would permit a particularly wide distribution of certain forms at that time. Though the lava beds appear to have been subjected to disturbance in some regions, the amount of movement was probably not sufficient to raise barriers which would offer important obstacles to the distribution of most mammalian forms. Judging by what we know of the mammalian faunas referred to the Middle Miocene of the West-American province, there was actually a notable uniformity in the life over this region during this epoch.

The distribution of the Miocene flows which seem to be related to the great sheets poured out in the Columbia River region has not been determined with exactness. Nevertheless one seems to be justified in certain suggestions as to the probable extension of this field to the north and south of the Columbia.

To the north of the Columbia, the lavas seem to be traced with certainty in eastern Washington, and upon them is found a sedimentary series known as the Ellensburg formation, which resembles in its general character the Mascall of Oregon. Such fossil remains as have been reported from these beds, particularly the plants, correspond to those of the Mascall.

To the south of the Columbia, the lava fields extend around

the Blue Mountains and cover the Oligocene John Day formation. In the valley of the John Day River near Dayville the Mascall Beds lie in a trough formed by the Columbia Lava faulted down against the older formations on the northern flank of this portion of the mountain mass. On the summit of the mountains the Columbia Lava appears again dipping gently to the south, where it seems to disappear beneath a formation resembling the Mascall. These beds contain a mammalian fauna similar to that in the Mascall on the northern flank of the mountains.

To the south of the Blue Mountains lies the extensive lava region in which the basaltic flows have been compared by Waring and others to the Columbia Lava, and upon a southern extension of an igneous series comparable to these flows rest the Virgin Valley Beds with a fauna similar to that of the Mascall.

It does not seem to the writer to be an absolutely safe conclusion that all of the igneous rocks included in the flows to which reference has been made are necessarily the exact equivalent of the main exposures on the Columbia River, or to this series as limited to the basalt flows which lie between the John Day Upper Oligocene and the Mascall Middle Miocene. Other igneous series both earlier and later are known, but there is a reasonable presumption in favor of considering the group of flows to which reference has just been made as belonging to the same general epoch. This epoch on the basis of correlation by mammalian palaeontology is referable to the Lower Miocene, as the beds immediately below it contain an Upper Oligocene fauna and those immediately above it a Middle Miocene fauna.

To the south of the Virgin Valley area in Nevada, the broken structure of the Basin region makes difficult the tracing of formations which are not quickly recognized by palaeontologic or petrographic species. There are, however, in this region exposures of beds which have superficially the appearance of the Miocene formations farther north, and which contain scattering remains of mammalian forms apparently later than early Miocene and older than Pleistocene. Exposures of this nature extend well through the state of Nevada, and may reach into the southern part of California. It is probable that a careful study

of the patches of sedimentary deposits extending through Nevada and into California will enable us to arrive at an approximate correlation of these formtaions.

As a few mammalian remains are found in the deposits of Tertiary age within the Great Valley of California it is hoped that correlation of these beds with the continental deposits of the Basin region may ultimately be possible. When this is accomplished we can determine the relationship of the continental beds to the well-known marine series of the Pacific Coast region.

The relation of the Columbia Lava series to the marine beds of Western Oregon should also furnish important information in any effort which may be made to correlate the continental formations with the marine series.

Relation of Virgin Valley Beds to Faulting Movements of Basin Region.—As nearly as can be determined, the Virgin Valley Beds rest unconformably upon the Cañon Rhyolite in Virgin Valley. There is reason to believe that these rhyolites represent the upper portion of the igneous series of Pueblo Range, and any disturbance which affected the rhyolites must have disturbed this basalt series. It is evident that considerable faulting movements have effected the basaltic series in comparatively late time, and other movements may have occurred between the Virgin Valley and Thousand Creek epochs. The amount and nature of these movements cannot be determined until the relation of the Virgin Valley and Thousand Creek Beds to each other is certainly known. If the Thousand Creek Beds were formed in post-Mesa-Basalt time and all of the beds below the Mesa Basalt are to be referred to one epoch, the Virgin Valley, there must have been profound movements in pre-Virgin Valley time, as the sediments below the Mesa Basalt have filled around prominent points consisting of the older igneous rocks. If the beds immediately below the Mesa Basalt are the equivalent of the Thousand Creek series, it is possible that considerable movements occurred after the deposition of the Virgin Valley and previous to the deposition of the uppermost beds. The presence of a marked unconformity below the rhyolitic gravels, which possibly separate upper and lower Virgin Valley divisions, is in favor of such a view. On the other hand, excepting at the

contact below the rhyolitic gravels there does not appear to be a noticeable difference in position between the upper and lower sedimentary beds below the Mesa Basalt; at any rate no such difference appears as would be produced if any considerable change in the topography had developed through faulting or other movements.

On any hypothesis excepting that the Thousand Creek Beds were formed by accumulation late in the history of the cutting of Virgin Valley, it would be impossible to avoid the conclusion that important faulting movements have occurred in this region in post-Thousand-Creek time.

Relation of Thousand Creek Beds to other Formations of the Pacific Coast and Basin Regions.—The unique character of the mammalian fauna found in the beds at Thousand Creek, and the imperfectly understood stratigraphic relations of the formation in which this fauna occurs make it difficult to estimate the position of the Thousand Creek Beds in the scheme of Pacific Coast formations. A possible relationship to the Rattlesnake Beds of the John Day Region in Oregon is the correlation which naturally suggests itself before any other. Correlation with other formations is also suggested, but the basis for comparison is very slight.

The type exposure of the Rattlesnake fortunately occurs in the same region with the typical section of the Mascall Miocene, and with well-marked Pleistocene deposits, so that the earlier and later limits of age of the Rattlesnake are quite clearly defined.

The typical Rattlesnake Beds rest in marked unconformity upon the Mascall along the border of the Blue Mountains in the vicinity of Dayville on the John Day River. The Mascall here occupies a trough formed on the north side by the Columbia Lava dipping to the south, and on the southern side by the mass of the Blue Mountains, the Columbia Lava being faulted or sharply folded against the northern side of this ridge of the mountains. The Mascall Beds agree in dip and strike, so far as observed, with the underlying Columbia Lava, and were deposited previous to the movement expressed in the sharp deformation of the lava. As the exposures of the Mascall are

between 1,000 and 2,000 feet thick, and are seen in the narrow trough because of deformation of the underlying lava since their deposition, it is evident that they originally existed outside this depression, but have been eroded away. The Rattlesnake rests in a very slightly inclined position upon the eroded edges of this steeply tilted Mascall, and it is clear that the time of beginning deposition of the Rattlesnake must have been separated from the closing of deposition of the Mascall by a period in which very marked deformation and extensive erosion of the Mascall occurred. It seems improbable that this deformation and erosion could have taken place in a period shorter than that represented by the Upper Miocene. This being the case the Rattlesnake would not be older than early Pliocene.

The upper limit of age of the Rattlesnake seems to be fixed by the beginning of the erosion period during which the great cañons of this region were cut. Terrace deposits near the floor of the present cañon of the John Day River contain undisturbed remains representing a Pleistocene fauna. The cañon-cutting period must, therefore, have ended sometime before the close of Pleistocene time. The presumption is that the cañon-cutting was accomplished in early Pleistocene time. As the John Day Cañon cuts through the typical Rattlesnake section, the upper limit of age of these beds seems determined as not later than the beginning of the Pleistocene.

The Rattlesnake Beds as we know them in the John Day Valley were evidently laid down in a basin of comparatively limited extent, which was bounded on the north by the Columbia Lava monocline, and reached south to the ridge of the Blue Mountains south of the John Day River. The greatest thickness of the beds known to the writer, including the maximum thickness of the various members of the series, would be a little less than 500 feet. A small part of the series consists of beds which have the appearance of old soil mantles, but the greater portion of the whole accumulation is made up of coarse gravel. The time required for the deposition of the whole thickness may, therefore, have been rather short, and presumably does not represent more than one-half of the Pliocene, in which it seems probable that the formation of this series of beds occurred.

There does not, however, seem to be anything in the physical evidence to indicate whether the deposition occurred in early or in late Pliocene time.

The only suggestion bearing upon the question as to the division of the Pliocene represented by the Rattlesnake Beds is offered by the fauna. The few species thus far found at the Rattlesnake exposures are unfortunately only poorly represented, and in a large percentage of cases the occurrence is not known exactly. Following is the list of species referred to this formation:

Neohipparion occidentale (Leidy).
Neohipparion sinclairi (Wortman).
Platygonus rex Marsh.
Pliohippus supremus (Leidy).
Canis (?) *davisi* Merriam?.
Clemmys hesperia Hay.
Rhinoceros, indet.
Camel, large, indet.
Camel, small, indet.
Suilline, large, indet.

Of the above forms the rhinoceros seems quite certainly not later than the earlier Pliocene, so that taking all evidence into consideration an approximation of the age of the Rattlesnake as early Pliocene seems justified.

Judging the age of the Thousand Creek and Rattlesnake Beds separately on the basis of available information both seem to fall within the Lower Pliocene. The meagre Rattlesnake fauna offers so little for comparison that faunal similarity between the two is not evident. The only parallels indicated are shown in the occurrence in both of rhinoceroses and large camels, together with horses having an advanced type of tooth structure. An additional suggestion appears in the presence in the Thousand Creek Beds of the canid species, *Canis* (?) *davisi*, which seems to be identical with a species doubtfully derived from the Rattlesnake at Rattlesnake Creek, Oregon.

In the region where the Thousand Creek Beds are exposed there are fortunately two important factors in the geologic sequence which seem to be almost identical with the physical factors which check the possible upper and lower limits of age of the Rattlesnake Beds in the John Day Valley: these factors

are the, (1) Virgin Valley Beds, corresponding to the Mascall; and (2), the great valleys, originating, like the valley of the John Day, through geologically recent erosion. If the relation of the Thousand Creek Beds to both of these factors were clearly shown, important evidence would be available for checking the relative ages of the two formations.

If the Thousand Creek Beds are pre-Mesa-Basalt, as seems possible, they may correspond closely in age to the Rattlesnake. It is perhaps worth noting that the remarkable extent of the layer of Mesa Basalt in the Virgin Valley region is paralleled, in a manner, by the great extent of the bed of Mesa Rhyolite, forming the mesa capping over a considerable part of the Rattlesnake.

If the Thousand Creek Beds are post-Mesa-Basalt they are either younger than the Rattlesnake or the cañon-cutting was initiated at an earlier date than in the region to the north of the Blue Mountains. As nearly as we are able to judge there seems reason to believe that the great cañons of the entire region under consideration owe their origin to an uplift of continental character, which occurred near the close of Pliocene time, and unless special conditions have been introduced in one or the other of the regions discussed we are presumably near the truth in considering the cañon-cutting as nearly coincident in the two areas. In that case post-Mesa Basalt age of the Thousand Creek Beds would place them at a much later date than the Rattlesnake. It would also evidently place them within the limits of Pleistocene time, which is clearly negatived by their fauna. It seems, therefore, that with the evidence at hand there is reason for considering the Thousand Creek Beds as pre-Mesa Basalt.

As will be seen, the lines, however drawn, seem to indicate that the Rattlesnake and Thousand Creek epochs are nearer to each other than either is to any other distinctly recognized epoch in the history of this region. There is, however, still reason for considering them as not necessarily identical. Such faunal evidence as is available does not by any means indicate contemporaneity, and the physical evidence of contemporaneous deposition is far from definite. It seems probable that additional

palaeontologic and geologic studies in both regions may ultimately give us a much more satisfactory statement of the relations than is now possible.

Of the formations in which mammalian fossils have been found west of the Sierra Range region there are none in which a sufficient representation is known to offer more than a mere suggestion as to time relationship to the Thousand Creek Beds. Four formations in California—the Pinole Tuff and Orindan freshwater formations of the San Francisco Bay region, and the largely marine Jacalitos and Etchegoin formations of the western San Joaquin Valley—contain fragmentary mammalian remains which suggest a late Miocene to Pliocene stage.

The Pinole Tuff, overlying the San Pablo formation at San Pablo Bay, contains a few fragmentary mammalian fossils, among which is a horse of an advanced protohippine type. The type of horse present here might represent late Miocene or early Pliocene. It is of a stage at least as advanced as that of the *Pliohippus* species found at Thousand Creek.

In the Orindan and Siestan formations which overlie the Pinole Tuff a few remains have been found at rather widely separated localities. They include a large mastodon, a species of *Neohipparion* near *N. richthofeni*, a small camel, a peccary, and the type specimen of *Eucastor lecontei*. This fauna would seem to represent a very late Miocene or early Pliocene stage, but occurs above the Pinole Tuff with *Pliohippus*.

In the Jacalitos formation of the western San Joaquin Valley, as also in the Etchegoin formation above it, scattered horse teeth have been found representing a species of *Pliohippus* about as advanced as that of the Pinole Tuff. Taken by itself, this form would be considered as representing late Miocene to Pliocene time.

The stages of evolution represented by the protohippine forms of the Pinole Tuff and the Etchegoin formation are approximately the same, so far as can be determined with the very fragmentary material at hand. They are also at approximately the stage of advance shown in the Thousand Creek species. This may, however, not be taken as suggesting more than that these California formations are to be included in a period covered

by the late Miocene and early Pliocene. They all belong in an epoch which follows the middle Miocene and precedes the middle Pliocene. Farther collections from the Californian formations will doubtless assist in determining their relationship to the Thousand Creek Beds more definitely.

SYSTEMATIC DESCRIPTIONS

Pisces

Scattered vertebrae and isolated skull bones of small fishes were found at locality 1090 in the Virgin Valley Beds, and at locality 1097 in the Thousand Creek Beds. The material was very fragmentary and a satisfactory determination of the forms represented seems improbable.

Reptilia

OPHIDIAN REMAINS

Several snake vertebrae were found in an exposure of the Thousand Creek Beds west of Railroad Ridge. They evidently belong to several individuals, and it is not certain that they all represent the same generic type. The vertebrae present are precaudals with well-marked rib attachments (see figs 1*a* and 1*b*). The imperfect development of the neural spines is presumably to be attributed to their having been located near the posterior portion of the rib-bearing division of the vertebral series. The zygosphene is large and the zygantral excavation deep. Hypapophyseal prominences are present, but are imperfectly developed.

Figs. 1*a* and 1*b*. Ophidian remains. Precaudal vertebrae. No. 19422, × 2. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 1*a*, posterior view; fig. 1*b*, lateral view.

Occurrence: Thousand Creek Beds; locality 1103, Thousand Creek region, west of Railroad Ridge, Humboldt County, Nevada.

CLEMMYS, sp.

A number of fragments representing testudinate forms (fig. 2) from locality 1090 in the Virgin Valley Beds were referred

to Dr. O. P. Hay for examination. Dr. Hay has very kindly furnished the following statement regarding these specimens. "I examined the pieces of turtles sent me and compared them especially with *Clemmys marmorata* from California. I see no reason why they may not belong to that genus, but they certainly are not *C. marmorata*. The material is so scanty that it seems to me better not to describe it, or at least not to name it."

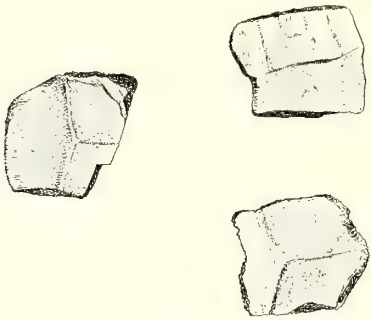


Fig. 2. *Clemmys*, sp. Peripheral elements. No. 19421, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

Occurrence: Virgin Valley Beds; locality 1090, Virgin Valley, Humboldt County, Nevada.

Aves

BRANTA, sp.

At two localities several miles apart in the Thousand Creek region, fragmentary specimens representing the ulna of a large species of goose (fig. 3) were found. These specimens were examined by Mr. L. H. Miller who has kindly furnished the following note regarding them.

"No. 12556 is the distal portion of the left ulna of a large anserine bird corresponding most closely in size with the Recent *Branta canadensis*. The fossil specimen slightly exceeds in size the only specimen of the Recent form available for comparison, but the difference is scarcely greater than exists within the range of the species as it is known today. There is no character that would exclude the specimen from the species *Branta canadensis* Linn. (?), although in the absence of a more complete specimen its assignment to this species must be a purely tentative procedure."

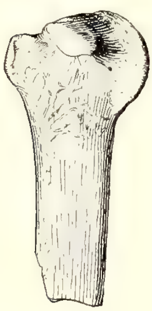


Fig. 3. *Branta*, sp. Distal portion of left ulna. No. 12556, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

The second specimen is identical in form with

the one described above by Mr. Miller, and is considered by him as representing the same species.

Occurrence: Thousand Creek Beds; localities 1063 and 1100, Thousand Creek, Humboldt County, Nevada.

INSECTIVORA

SCAPANUS(?), sp.

From two localities in the Thousand Creek region remains representing moles have been obtained. The only specimens recognized thus far consist of the humeri (figs. 4*a* and 4*b*), which do not seem to furnish characters clearly distinguishing them from the existing moles of the West Coast region. It is not improbable that more material would show peculiar generic characteristics in the Thousand Creek forms. The presence of moles at two localities in the Thousand Creek Beds seems to indicate a soil more humid at these localities than the average soil in this region at the present time. This may, however, be due to purely local conditions of humidity, such as obtain at the present time in restricted areas of the Great Basin region.

4*a* 4*b*

Figs. 4*a* and 4*b*. *Scapanus*(?), sp. Right humerus. No. 19409, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 4*a*, anterior view; fig. 4*b*, posterior view.

Occurrence: Thousand Creek Beds; localities 1103 and 1097, Thousand Creek, Humboldt County, Nevada.

CARNIVORA

CANIDAE

TEPHROCYON KELLOGGI, n. sp.

Type specimen a lower jaw with dentition, no. 11562, Univ. Calif. Col. Vert. Palae. From the Virgin Valley formation at Virgin Valley, Humboldt County, Nevada. The species is named in honor of Miss Louise Kellogg, who discovered the type specimen.

The genus *Tephrocyon* is represented by several specimens

referred to a species distinct from the typical *T. rurestris* of the Mascall formation in the John Day region of Oregon. Through the kindness of Professor John F. Bovard and Professor Arthur J. Collier, the type specimen of the Mascall species was loaned by the University of Oregon for comparison.

The jaw is of nearly the same length as in the type species, but more slender and the inferior margin not so strongly convex below the anterior end of the masseteric fossa. Inferior premolar series longer, and molar series shorter than in *T. rurestris.* P_1, P_2, and P_3 of the type specimen without anterior or posterior cusps. P_4 with a single posterior cusp. M_1 with large metaconid, heel with large crushing hypoconid and entoconid. Trigonid of M_2 with well-developed paraconid.

The form of the mandible (pl. 32) in this species differs less noticeably from that of the typical *Canis* than in the type specimen of *Tephrocyon.* The inferior margin is not as strongly convex as in *T. rurestris,* nor is the jaw as a whole quite as massive. The jaw tends, however, to be relatively heavy in the posterior half in comparison with species of *Canis.*

The incisor teeth are not present on any specimen, and the canines are represented only by the basal portion of a tooth not showing any peculiar characters.

The premolars are uncommonly simple in form on the type specimen of this species. There appear to be no subsidiary cusps on the first three premolars, but P_4 has in addition to the principal cone a posterior cusp and an incipient basal tubercle. On another specimen, no. 11474, apparently representing this form, P_2 has a distinct posterior cusp.

M_1 is characterized by the large size of the metaconid and of the broad crushing heel (see pl. 32, fig. 1). The metaconid is larger and more prominent than in *T. rurestris.* The heel of this tooth is nearly identical in form with that of the type species. The hypoconid and entoconid are of approximately equal size, but the entoconid seems to be slightly more elevated. There is a small but distinct tubercle on the posterior side of the base of the protoconid immediately in front of the hypoconid. Another small tubercle is faintly developed on the posterior side of the base of the metaconid.

1

2

Tephrocyon kelloggi, n. sp.

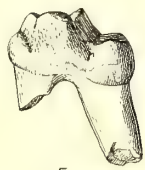
Fig. 1. Right mandible. Type specimen, no. 11562, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 2. Left mandible. Type specimen, no. 11562, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

M_2 is relatively large, and an extraordinarily developed tooth. Its fore and aft diameter equals almost three-fourths that of the carnassial, and there is a well-developed paraconid present. The protoconid and the metaconid are nearly equal in size. The paraconid may nearly equal the other cones in size. On the large basin-shaped heel the nearly equally developed hypoconid and entoconid are connected posteriorly by a low marginal ridge. On the antero-external side of the base of the trigonid a prominent ridge is developed on the cingulum. On the specimens available a minute tubercle is present in the valley between the protoconid and hypoconid.


5b


6


5a


7

Figs. 5*a* and 5*b*. *Tephrocyon kelloggi*, n. sp. M_2, unworn tooth. No. 10651, × 1½. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 5*a*, outer side; fig. 5*b*, superior side.

Fig. 6. *Tephrocyon kelloggi*, n. sp. M_2, worn tooth. No. 11474, × 1½. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 7. *Tephrocyon*, near *kelloggi*, n. sp. M_2. No. 12542, × 1½. Thousand Creek Beds, Thousand Creek, Nevada.

M_3 is not represented on any of the specimens. Judging from the form and size of the alveolus, this tooth was relatively large, and its anteroposterior diameter was considerably greater than the transverse.

Measurements.

	Type specimen, no. 11562
Length of mandible from anterior side of P_1 to posterior side of condyle	103.7 mm.
Height of mandible below protocone of M_1	21.
Greatest thickness of mandible below talonid of M_2	9.
P_2, anteroposterior diameter	6.
P_3, anteroposterior diameter	6.7
P_4, anteroposterior diameter	8.4
M_1, anteroposterior diameter	15.
M_1, anteroposterior diameter of heel	4.
M_1, transverse diameter of heel	7.
M_2, anteroposterior diameter	10.5
M_2, greatest transverse diameter	6.7

	No. 10651
M_2, anteroposterior diameter	11.5 mm.
M_2, greatest transverse diameter	6.9

In its most distinctive characters, that is in the form of M_1 and M_2, this species resembles the typical *Tephrocyon,* and is evidently closely allied to it. It differs from the type species in the simpler premolars, larger metaconid of M_1, and relatively larger M_2. The simplicity of the premolars, if found to occur regularly in a large series of specimens, might, taken with other differences, be advanced as evidence of subgeneric separation. It should, however, be noted that on one specimen, no. 11474, a distinct posterior cusp is developed on P_2, though the dentition is otherwise quite similar to the type specimen of *T. kelloggi,* and there seems hardly sufficient reason for specific separation.

The characters of the dentition in *Tephrocyon* as represented in *T. kelloggi* are in some respects quite bear-like. The second molar is unusually large, its anteroposterior diameter equalling over seventy per cent of that in M_1. The anteroposterior diameter of M_2 nearly equals that of the corresponding tooth in *T. rurestris,* while in that species the carnassial is one-third larger than in *T. kelloggi.* In the carnassial the large heel and the extraordinarily developed metaconid give an unusual crushing surface. Judging from the size of the alveolus M_3 was relatively larger than in *T. rurestris.*

Such ursine characters as appear in the dentition of this form are probably not to be considered as indicating that it is in any sense ancestral to the bears. The great variety of canids with bear-like characters which is being found in the middle Tertiary faunas does, however, suggest the possibility of independent origin of certain of the groups which have been brought together in the Ursidae.

Occurrence: Virgin Valley Beds; locality 1065, Virgin Valley, Humboldt County, Nevada.

TEPHROCYON, near KELLOGGI, n. sp.

A single second lower molar of *Tephrocyon* (no. 12542, fig. 7) was found in the beds at Thousand Creek. This specimen very closely resembles M_2 of the type specimen of *T. kelloggi,*

but is slightly shorter and is a little narrower posteriorly. It is hardly to be distinguished from *T. kelloggi* and may be referred to that species tentatively.

Occurrence: Thousand Creek Beds; locality 1103, Thousand Creek, Humboldt County, Nevada.

Measurements, No. 12542.

M_2, anteroposterior diameter	9.9 mm.
M_2, greatest transverse diameter	5.7

TEPHROCYON(?), compare RURESTRIS (Condon)

In the collection from Little High Rock Cañon there is a fragment of a lower jaw (figs. 8*a* and 8*b*) with P_4 and M_1 which represents a canid. This specimen, no. 12503, differs in form and dimension of P_4 and M_1 from the type specimen of *T. rurestris.* P_4 is a rather heavy tooth with both posterior cusp and basal tubercle. As in *T. rurestris* there is no anterior basal tubercle. In M_1 the metaconid seems relatively smaller than in the typical species, but it is not easy to judge of this character with absolute certainty, as the two teeth are not available in the same stage of wear. The heel of M_1 is wide, while the hypoconid and entoconid are of nearly equal size.

M_1 of this form may differ from *T. rurestris* in acuteness of the protoconid and paraconid, and in smaller size of the metaconid. Otherwise the resemblance is very close. As no. 12503 has an absolutely unworn M_1, while in the type of *T. rurestris* this tooth is considerably worn, the difference may appear slightly exaggerated. It is desirable to have M_2 represented before attempting to establish the identity of the two forms with certainty.

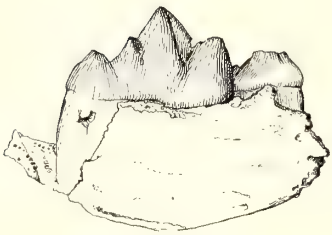
Occurrence: Virgin Valley Formation; locality, Little High Rock Cañon, Humboldt County, Nevada.

Measurements

	Type of *T. rurestris*	No. 12503
P_4, anteroposterior diameter	11.5 mm.	11.7
P_4, transverse diameter	6.	6.3
M_1, anteroposterior diameter	20.	22.3
M_1, anteroposterior diameter of heel	6.	6.4
M_1, transverse diameter of heel	....	8.4
Height of mandible below protocone of M_1	20.	....

8b

9b



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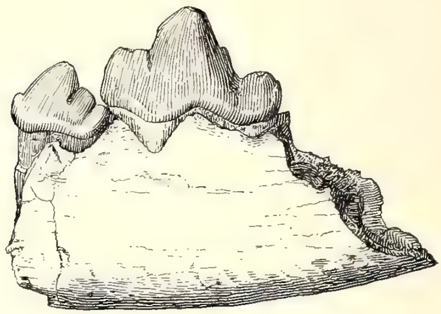

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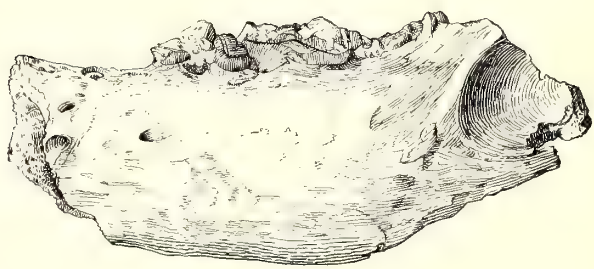

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Figs. 8*a* and 8*b*. *Tephrocyon*(?), compare *rurestris* (Condon). No. 12503, natural size. Virgin Beds, Little High Rock Cañon, Nevada. Fig. 8*a*, M_1 and P_4, inner side; fig. 8*b*, M_1, superior view.

Figs. 9*a* and 9*b*. *Tephrocyon*(?), sp. *a*. M_1 and P_4. No. 12504, natural size. Virgin Valley Beds, High Rock Cañon, Nevada. Fig. 9*a*, outer side; fig. 9*b*, superior view.

Fig. 10. *Aelurodon*(?), sp. A portion of the lower jaw. No. 12545, × ⅔. Virgin Valley Beds, High Rock Cañon, Nevada.

TEPHROCYON(?), sp. *a*.

The jaw fragment no. 12504 from High Rock Cañon (figs. 9*a* and 9*b*) represents a form not differing greatly from the specimen tentatively referred to *T. rurestris*. The teeth on this specimen are somewhat larger than in the type of *T. rurestris;* P_4 is somewhat thinner and possesses an anterior basal tubercle; and the tubercles on the heel of M_1 are quite uneven in size, the entoconid being considerably smaller than the hypoconid.

There may be some doubt as to whether this specimen actually represents the genus *Tephrocyon*. In so far as it differs from *Tephrocyon* it approaches the dogs of the *Canis* type.

MEASUREMENTS

P_4, anteroposterior diameter	12.7 mm.
P_4, transverse diameter	5.6
M_1, anteroposterior diameter	24.2
M_1, anteroposterior diameter of heel	6.4
M_1, transverse diameter of heel	8.4
Height of mandible below protocone of M_1	25.

AELURODON(?), sp.

A fragment of a large jaw (no. 12545) from High Rock Cañon (fig. 10) represents a form certainly quite different from any of the species mentioned above. The jaw is very short and massive. The dental series includes three molars and at least three premolars, though the alveoli of the anterior premolars are not clearly shown. The inferior carnassial has about the same anteroposterior diameter as in specimen 12504 referred to tentatively as *Tephrocyon*(?), sp. *a*, but the relation of the dimensions of this tooth to those of the jaw are entirely different. This specimen evidently represents a type generically different from the forms referred to *Tephrocyon*. The short massive mandible suggests *Aelurodon,* though the teeth seem to be relatively small and weak for any of the species thus far described in that genus.

Occurrence: Virgin Valley Formation, High Rock Cañon, Humboldt County, Nevada.

MEASUREMENTS

Height of mandible below protoconid of M_1	39. mm.
Thickness of mandible below protoconid of M_1	12.
M_1, approximate anteroposterior diameter	25.

CANIS(?) DAVISI, n. sp.

Type specimen, no. 545, Univ. Calif. Col. Vert. Palae. Mascall(?) beds near Rattlesnake Creek, John Day Valley, Oregon, figured and described without specific designation by J. C. Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 5 and 6, fig. 1.

A single first upper molar from Thousand Creek (fig. 11)

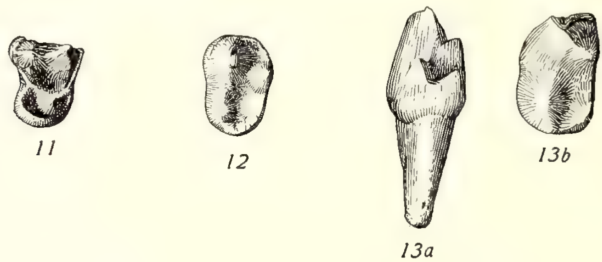


Fig. 11. *Canis*(?) *davisi*, n. sp. M^1. No. 12505, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 12. *Canis*(?), sp.; near *davisi*. M_2, seen from above. No. 12543, × 1½. Thousand Creek Beds, Thousand Creek, Nevada.

Figs. 13*a* and 13*b*. *Canis*(?), sp.; near *davisi*. M_1. No. 12543, × 1½. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 13*a*, posterior view; fig. 13*b*, posterior region of the tooth seen from above.

shows the same characters as M^1 in the specimen described some years ago from near Rattlesnake Creek, Oregon, and may be referred to that species.

In the type specimen the molars are a little smaller than in the living coyotes of eastern Oregon and M^2 is relatively a little larger than in the Recent species. The outer cusps of M^1 are laterally compressed to such an extent that the cusps are noticeably sharp. The protocone together with the incipient protoconule and metaconule form a wide and sharply-marked V-ridge. The high and narrow hypocone swings forward to a point approximately even with the apex of the protocone.

The molar tooth from Thousand Creek is almost identical with the type specimen in form. The hypocone of M^1, which was somewhat worn in the type, is here complete, and shows this tooth to be a little wider transversely than in the original figure of the type specimen.

Occurrence: Mascall or Rattlesnake Beds, eastern Oregon; locality 1101, Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

MEASUREMENTS

	No. 545	No. 12505
M^1, anteroposterior diameter	9.7 mm.	9.9
M^1, anteroposterior diameter at narrowest point between protocone and paracone	7.3	7.6
M^1, transverse diameter	13.3	*a*12.5

a approximate, outer edge broken.

CANIS(?), sp.; near DAVISI, n. sp.

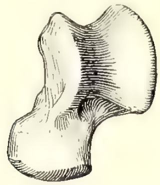
A complete second lower molar (fig. 12) and the posterior portion of a lower carnassial (figs. 13*a* and 13*b*) from Thousand Creek, represent a small canid species apparently not far removed from the existing *Canis*.

The trigonid portion of M_2 consists of a small but nearly centrally located protoconid and a considerably reduced metaconid. The heel consists of a small hypoconid with a basin-like expansion of the entoconid region. The form of this tooth is near that of M_2 in some of the existing forms of *Canis*, and there seems reason for considering that this specimen represents a form near that genus.

On the fragment representing the lower carnassial, the metaconid is of moderate size. On the heel the hypoconid is considerably larger than the entoconid, and is distinctly compressed laterally, as is the entoconid also. This tooth was probably, but not certainly, associated with the second lower molar described above.

This form is quite distinct from the species of *Tephrocyon* in the structure of M_2, and in the form of the heel of M_1. The heel of the inferior carnassial is narrower than in *Tephrocyon*, the tubercles are distinctly compressed laterally, and the entoconid is relatively small. M_1 differs also from the forms referred to *Tephrocyon*(?), sp. *a* and *T.* cf. *rurestris* in the narrowness of the heel, and in the compression of its tubercles.

It seems to the writer not improbable that the inferior molars in no. 12543 are from an animal of the same species as the upper molar referred to as *Canis davisi;* at any rate they represent a closely similar canid type.



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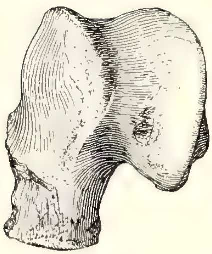

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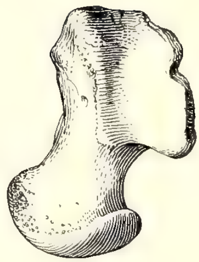

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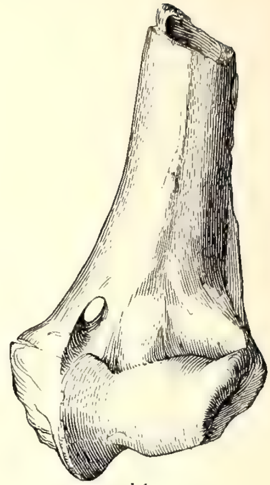

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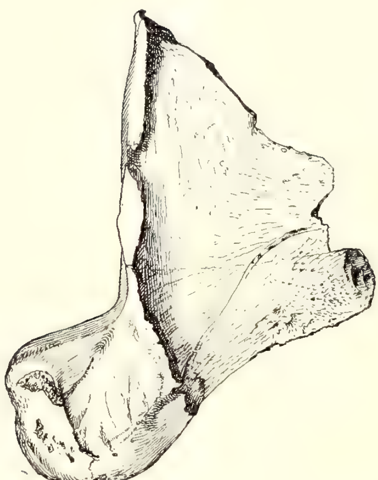

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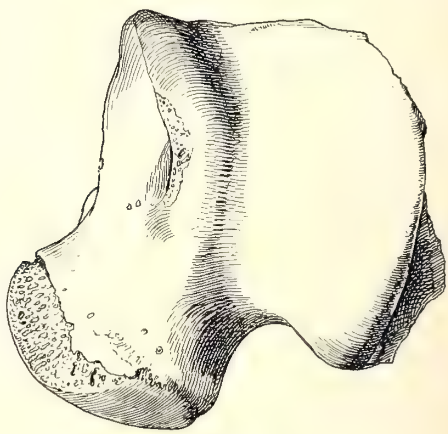


19

Fig. 14. Distal end of humerus. Genus indet. No. 10650, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 15. Astragalus of small canid. *Tephrocyon* (?). No. 12547, natural size. Thousand Creek Beds ?, Thousand Creek, Nevada.

Fig. 16. Astragalus of canid. No. 19410, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 17. *Felis*, sp. *b*. Astragalus. No 12546, natural size Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 18. *Felis*, sp. *a*. Terminal phalange. No. 12551, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 19. *Felis*, sp. *a*. Astragalus. No. 19411, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

Occurrence: Thousand Creek Beds; locality 1100, Thousand Creek, Humboldt County, Nevada.

Measurements

	No. 12543
M_1, anteroposterior diameter of heel	5.5 mm.
M_1, transverse diameter of heel	6.4
M_2, anteroposterior diameter	8.5
M_2, transverse diameter	6.

CANID, FORMS INDETERMINATE

A number of scattered limb bones from Virgin Valley and Thousand Creek represent several canid forms, and possibly belonging to some of the species described above.

Several small astragali (fig. 15) obtained at different localities are apparently to be referred to the same form, which is possibly a species of *Tephrocyon.* They are characterized by a sharply-defined shelf at the anterior end of the trochlea and by the rather marked lateral twist of the neck.

An astragalus representing another type of canid is shown in figure 16.

INDETERMINATE HUMERI

The distal end of a carnivore humerus from Virgin Valley (no. 10650) and one from Thousand Creek (no. 12553) represent two distinct generic types. Both may be feline or they may both represent a primitive dog-like form.

In specimen 10650 (fig. 14) the broad distal region of the humerus shows a strongly developed inner condyle and supinator ridge, and a large supracondyloid foramen is present. The supinator ridge extends upward as a sharp ridge to the narrowest portion of the shaft, where the bone is broken off.

In specimen no. 12553 the distal end is no wider than in no. 10650, and the shaft is much smaller, but the anteroposterior diameter of the trochlea is much greater. The olecranon fossa is also much larger than in no. 10650.

MEASUREMENTS OF HUMERUS

	No. 10650	No. 12553
Greatest width of distal end	35.8 mm.	....
Width from bottom of trochlear groove to extreme outer side	18.4	18.4
Least anteroposterior diameter of trochlea	8.2	11.6
Width measured from middle of lower end of supracondyloid foramen to outer condyle	27.	27.
Anteroposterior diameter of shaft forty-five millimeters above the distal end	12.4	10.

PROCYONIDAE

PROBASSARISCUS ANTIQUUS MATTHEWI, new genus and new variety

Type specimen no. 12539, Univ. Calif. Col. Vert. Palae. From the Virgin Valley Beds; locality 1095, Virgin Valley, Humboldt County, Nevada.

Probassariscus, new genus. Characterized by the presence of a well-developed paraconid ridge on M_2, and by the greater width of the heel and better development of the entoconid region of M_2 than in *Bassariscus.*

In the collections from Virgin Valley there is a single lower jaw fragment, with the posterior four teeth (figs. 21*a* and 21*b*), which represents a form closely related to the form described as *Bassariscus antiquus* from the Snake Creek Beds of western Nebraska. The differences in dimensions which appear are not considered for the present as indicating more than a varietal separation from the Snake Creek species. The Virgin Valley form is named in honor of Dr. W. D. Matthew.

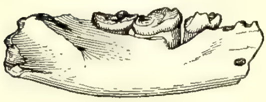
The jaw fragment represents an animal of approximately the same size as the Recent *B. astuta.* The mandible is slightly higher than that of the Recent specimens used for comparison, but is not thicker. A large mental foramen is present below the middle of P_3. A much smaller foramen is present in *B. astuta* under the anterior root of this tooth.

In the inferior dental series of the specimen from Virgin Valley, M_1 is absolutely smaller and M_2 absolutely larger than in the living species, and M_2 is relatively considerably larger than

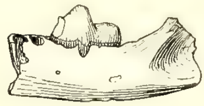
[10] Matthew, W. D., & Cook, H. J., Bull. Am. Mus. Nat. Hist., vol. 26, p. 377, 1909.

21b

22b



21a



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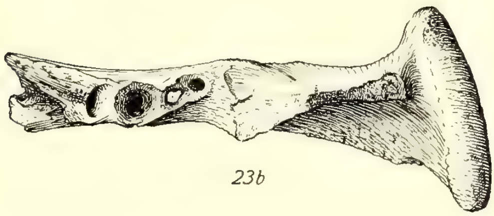
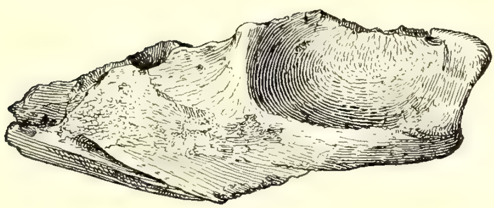


23b



23a

Figs. 21*a* and 21*b*. *Probassariscus antiquus matthewi*, n. gen. and n. var. Mandible with dentition. Type specimen, no. 12539, natural size. Virgin Valley Beds. Virgin Valley, Nevada. Fig. 21*a*, outer side; fig. 21*b*, superior view.

Figs. 22*a* and 22*b*. *Mustela furlongi*, n. sp. Fragment of mandible with M_1. Type specimen, no. 12540, × 2. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 22*a*, outer side; fig. 22*b*, superior view.

Figs. 23*a* and 23*b*. Mustelid, indet. Fragment of lower jaw. No. 12555, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 23*a*, outer side; fig. 23*b*, superior side.

in either the Recent species or the form from the Snake Creek Beds.

P_3 is represented only by alveoli of the two roots. P_4 is slightly larger than in the modern *B. astuta.* The crown is not satisfactorily shown, but the posterior cusp seems to have been wider than in the living species.

M_1 is unfortunately considerably worn, but is evidently closely similar in form to the corresponding tooth of the living species. The paraconid is possibly slightly thicker transversely, or is turned so that its blade is more nearly transverse to the anteroposterior axis of the tooth.

M_2 differs from the corresponding tooth of *B. astuta* in its relatively larger size, and in the presence of a distinct paraconid ridge. Owing to the worn condition of this tooth it is not possible to determine exactly the stage of development of the paraconid. A paraconid is also shown in the illustration of the type specimen of *P. antiquus* from Snake Creek. The talonid region differs from that of *B. astuta* in its greater width. The form and position of the tubercles are much the same as in the Recent species, excepting that the region of the entoconid is more elevated and is separated from the metaconid by a sharp fissure.

The Virgin Valley specimen is certainly closely related to that described by Matthew and Cook from the Snake Creek Beds. In both forms the paraconid is present on M_2, whereas it is absent entirely in the living species. M_2 is also relatively large compared with the inferior carnassial in both.

Occurrence: Virgin Valley Beds, locality 1095, Virgin Valley, Humboldt County, Nevada.

MEASUREMENTS

	P. antiquus matthewi	*P. antiquus*	*B. astuta*
Length, P_4 to M_2 inclusive	17.6 mm.	17.4	17.3
Depth of jaw below M_1	7.8	7.	6.8
P_4, anteroposterior diameter	5.2	----	5.
M_1, anteroposterior diameter	6.8	7.9	7.5
M_1, greatest transverse diameter	3.8	3.8	3.7
M_2, anteroposterior diameter	5.5	5.9	5.2
M_2, greatest transverse diameter	3.5	3.5	3.2

URSIDAE(?)

URSUS(?), sp.

A large terminal phalange, no. 12554 (fig. 20), from the Thousand Creek Beds at locality 1100 at Thousand Creek, closely resembles the terminal phalanges of the bears, but may represent a very large canid form.

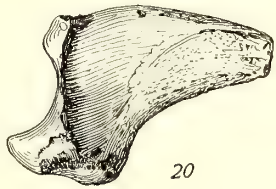


Fig. 20. *Ursus*(?), sp. Terminal phalange. No. 12554, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

MUSTELIDAE

MUSTELA FURLONGI, n. sp.

Type specimen, a lower jaw fragment with complete carnassial tooth, no. 12540, Univ. Calif. Col. Vert. Palae. From Thousand Creek Beds; locality 1103, Thousand Creek, Humboldt County, Nevada.

In the collections from near Thousand Creek there are two fragments of lower jaws with carnassials which represent an exceedingly small musteline species. The mandible of the smaller specimen measures only about three and one-half millimeters in height below the carnassial. The jaws are also apparently rather slender, and the anterior end of the masseteric fossa does not extend as far forward as in most of the modern forms. (See figs. 22*a* and 22*b*).

M_1 possesses a well developed metaconid and a long basin-like heel. The metaconid is relatively a little larger than in the modern species of *Mustela.* The long, wide heel is bordered by a prominent horseshoe-shaped marginal wall. M_2 is not present, but the tooth must have been much reduced, as the alveolus for the single root is small. P_4, as shown in specimen 12540, is two-rooted.

This species is somewhat more primitive than the Recent *Mustela* in the form of the trigonid of M_1, while the inner wall of the heel of this tooth is somewhat higher. More complete material may show that this form is generically distinct from the species grouped under the typical *Mustela.* In view of its

evident close relationship to these forms it may be classed with them until more material is obtained.

Occurrence: Thousand Creek Beds; locality 1103, Thousand Creek, Humboldt County, Nevada.

MEASUREMENTS

	No. 12541	No. 12540
Height of mandible below protoconid of M_1	4.3 mm.	3.4
M_1, anteroposterior diameter	5.8	5.1
M_1, transverse diameter	2.5	2.
M_1, anteroposterior diameter of heel	2.1	1.6
M_2, anteroposterior diameter of alveolus	1.5	1.4

MUSTELID(?), indet.

The posterior half of a lower jaw (no. 12555, figs. 23*a* and 23*b*) lacking the teeth and the coronoid process possibly represents a large mustelid form. The inferior margin of the mandible is more strongly convex below the anterior region of the masseteric fossa than in most of the existing mustelids, but approximates the form in *Potamotherium lacota* in this respect. The angle is broad and much flattened inferiorly, and approaches the condyle very closely. The masseteric fossa is short and deep. The dental foramen is situated only a short distance below a line connecting the posterior margin of the alveolus of the last molar and the inferior border of the condyle.

The alveoli of two molars are present. The posterior tooth was two-rooted and situated slightly transverse to the anteroposterior axis of the jaw. The posterior portion of this tooth rested partly on a distinct inwardly projecting prominence of the alveolar margin which extends well behind the anterior border of the coronoid process. On the second tooth from the posterior end of the inferior series the posterior root was circular in cross-section and considerably flared above. The anterior root is narrowed anteroposteriorly, and stands transverse to the long axis of the jaw. The form of the anterior root of this tooth is not that below the ordinary cutting blade on the trigonid region of M_1 in most carnivores. Either this alveolus represents the anterior root of a M_2, in which case M_3 would also be two-

rooted, or the carnassial was short and the trigonid portion of a distinctly crushing type. As the jaw was evidently short and massive it is improbable that a two-rooted M_3 was present; in other words the carnassial was presumably of a crushing type.

With the information available it is not advisable to attempt a definite correlation of this form with any known type. It is perhaps significant that Matthew and Cook describe, from the Snake Creek Pliocene, a mustelid which differs from *Potomotherium* in the presence of a two-rooted M_2.

Occurrence: Thousand Creek Beds; locality 1103, Thousand Creek, Humboldt County, Nevada.

FELIDAE

FELIS, sp. *a*.

Numerous isolated limb bones including astragali, a calcaneum, phalanges, metatarsals, and portions of the radius and ulna represent a large feline form exceeding average specimens of the Recent African lion in size. (See figs. 18 and 19). These specimens are comparable to the fragmentary material described from the Snake Creek Beds by Matthew and Cook, or to the large cats described as *Felis maxima* by Scott and Osborn[11], from the Loup Fork of Kansas.

Judging from the number of loose fragments found, this species, or group of species, was not uncommon in the Virgin Valley and Thousand Creek faunas and seems to have been an important element in the West-American Carnivora at this time.

Whether the species represented by the material at hand was machaerodont or typically feline is not definitely determined.

Occurrence: Virgin Valley Beds; locality 1064, Virgin Valley, Nevada; Thousand Creek Beds; locality 1063, 1096, 1097, 1099, 1100, 1101, Thousand Creek, Humboldt County, Nevada.

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[11] Scott, W. B., and Osborn, H. F., Bull. Mus. Comp. Zool., vol. 20, p. 70, 1890.

MEASUREMENTS

Ulna, no 12552.	
Least anteroposterior diameter behind sigmoid cavity	38.4 mm.
Anteroposterior diameter measured across the coronoid process	63.5
Astragalus, no. 11891.	
Greatest anteroposterior diameter	63.5
Greatest width across the trochlea	43.
Length of neck	24.5
Astragalus, no. 12548.	
Greatest anteroposterior diameter	60.5
Greatest width across the trochlea	42.
Length of neck	21.5
Metatarsal II, no. 12549.	
Anteroposterior diameter of proximal end	35.8
Transverse diameter of middle of shaft	16.
Metatarsal III, no. 12550.	
Anteroposterior diameter of proximal end	40.
Transverse diameter of shaft immediately below lateral articular faces of proximal end	20.8
Phalange III, no. 12551.	
Height of phalange from lower side of basal process to summit of core (exclusive of hood)	63.7
Greatest transverse diameter of middle region of phalange	24.2

FELIS, sp. *b*

A broken astragalus and a middle phalange, no. 12546, from the Thousand Creek region represent a feline species about as large as the existing cougar (see fig. 17).

MEASUREMENTS OF ASTRAGALUS, NO. 12546

Greatest anteroposterior diameter	32.8 mm.
Greatest width across the trochlea	19.

Occurrence: Thousand Creek Beds; locality 1104, Thousand Creek, Humboldt County, Nevada.

RODENTIA

The numerous rodent forms in the fauna of Virgin Valley and Thousand Creek have already been described by Miss Louise Kellogg[12] and by Mr. E. L. Furlong.[13] Fifteen species are listed

[12] Rodent Fauna of the Late Tertiary Beds at Virgin Valley and Thousand Creek Nevada, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 421–437, 1910.

[13] An Aplodont Rodent from the Tertiary of Nevada, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 397–403, 1910.

by Miss Kellogg, of which five occur at Virgin Valley and thirteen at Thousand Creek. Three species, *Aplodontia alexandrae, Mylagaulus monodon,* and *Lepus vetus* are common to the two faunas.

The species are distributed as follows:

Virgin Valley	Thousand Creek
Aplodontia alexandrae Furlong.	*Arctomys nevadensis* Kellogg.
Mylagaulus monodon Cope.	*Arctomys minor* Kellogg.
Mylagaulus pristinus Douglass.	*Citellus,* sp.
Palaeolagus nevadensis Kellogg.	*Aplodontia alexandrae* Furlong.
Lepus vetus Kellogg.	*Mylagaulus monodon* Cope.
	Eucastor lecontei (Merriam, J. C.) ?
	Dipoides, sp.
	Entophtychus minimus Kellogg.
	Peromyscus antiquus Kellogg.
	Peromyscus (?), sp.
	Diprionomys parvus Kellogg.
	Diprionomys magnus Kellogg.
	Lepus vetus Kellogg.

SCIURIDAE

ARCTOMYS NEVADENSIS Kellogg

Arctomys nevadensis Kellogg, Univ. Calif. Publ. Bull. Dept. Geol., vol. p. 422, figs. 1*a* to 2, 1910.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

ARCTOMYS MINOR Kellogg

Arctomys minor Kellogg, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 425, figs. 3 to 7, 1910.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

CITELLUS, sp.

Citellus, sp., Kellogg, Miss Louise, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 427, fig. 8, 1910.

A fragmentary specimen comprising a part of the lower jaw with M_1, apparently represents this genus.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

APLODONTIDAE

APLODONTIA ALEXANDRAE Furlong

Aplodontia alexandrae Furlong, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 397–403, figs. 1 to 5*c*, 1910.

Occurence: Rare in Virgin Valley Beds, Virgin Valley, Nevada; numerous specimens found in the Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

MYLAGAULIDAE

MYLAGAULUS MONODON Cope

Mylagaulus monodon, Kellogg, Miss Louise, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 427, figs. 9*a* to 10*b,* 1910.

Occurrence: Virgin Valley Beds, Virgin Valley, Nevada; Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

MYLAGAULUS PRISTINUS Douglass

Mylagaulus pristinus, Kellogg, Miss Louise, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 429, figs. 11*a* to 12*b*, 1910.

Occurrence: Virgin Valley Beds, Virgin Valley, Humboldt County, Nevada.

CASTORIDAE

EUCASTOR LECONTEI (Merriam, J. C.)

Eucastor lecontei (Merriam), Kellogg, Miss Louise, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 430, fig. 13, 1910.

Occurrence: Thousand Creek Beds ?, at Thousand Creek, Humboldt County, Nevada.

DIPOIDES, sp.

Dipoides, sp., Kellogg, Miss Louise, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 431, fig. 14, 1910.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

GEOMYIDAE

ENTOPHTYCHUS MINIMUS Kellogg

Entophtychus minimus Kellogg, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 431, fig. 15, 1910.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

CRICETIDAE

PEROMYSCUS ANTIQUUS Kellogg

Peromyscus antiquus Kellogg, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 433, fig. 16, 1910.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

PEROMYSCUS(?), sp.

Peromyscus(?), sp., Kellogg, Miss Louise, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 433, 1910.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

HETEROMYIDAE

DIPRIONOMYS PARVUS Kellogg

Diprionomys parvus Kellogg, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 433, figs. 17*a* and 17*b*, 1910.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

DIPRIONOMYS MAGNUS Kellogg

Diprionomys magnus Kellogg, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 434, fig. 18, 1910.

Occurrence: Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.

LEPORIDAE

PALAEOLAGUS NEVADENSIS Kellogg

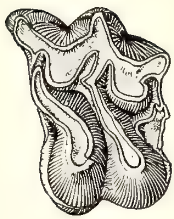
Palaeolagus nevadensis Kellogg, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 435, figs. 19*a* and 19*b*, 1910.

Occurrence: Virgin Valley Beds, Virgin Valley, Humboldt County, Nevada.

LEPUS VETUS Kellogg

Lepus vetus Kellogg, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 436, fig. 20, 1910.

Occurrence: Virgin Valley Beds, Virgin Valley, Nevada; Thousand Creek Beds, Thousand Creek, Humboldt County, Nevada.



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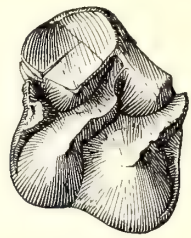

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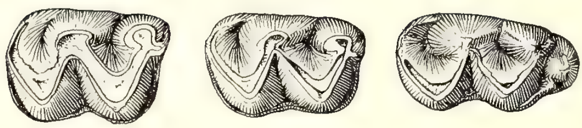

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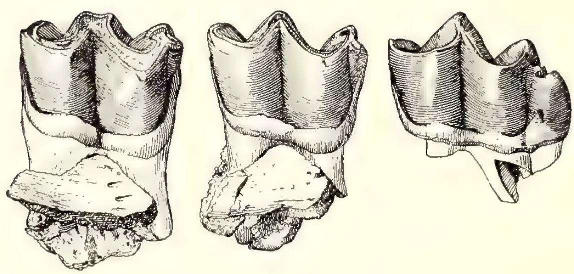

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Fig. 24. *Hypohippus*, sp. Upper molar. No. 12564, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 25. *Hypohippus*, near *osborni* Gidley. Upper molar. No. 11570, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 26. *Hypohippus*, near *osborni* Gidley. M_1 to M_3, occlusal view. No. 11760, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 27. Same as fig. 26, outer side, natural size.

Ungulata

EQUIDAE

Remains of horses are among the most common fossils at both Virgin Valley and Thousand Creek. In the small collection of fragmentary material obtained by Mr. Smith and the writer in 1906 Mr. Gidley[14] found at least five species represented. The material obtained during the past season unfortunately consists only of scattered teeth and limb bones. It is, however, sufficient to add considerably to what has been known regarding this group.

The forms present represent the genera *Hypohippus, Parahippus, Merychippus, Pliohippus*(?), and possibly *Equus.*

An examination of the collection according to localities shows that *Hypohippus, Parahippus* and *Merychippus* are found only in the Virgin Valley Beds, and do not appear at all in the deposits at Thousand Creek, while *Pliohippus*(?) and *Equus* are found at Thousand Creek and not in Virgin Valley.

HYPOHIPPUS, near OSBORNI Gidley

There is a considerable number of specimens of teeth and limb-bones which are to be referred to this genus. The specific characters, so far as determinable, represent a form combining to some extent the characters of *Hypohippus equinus* of the Deep River Beds of Montana and *H. osborni* from the Pawnee Creek Beds of Colorado. Until both the typical Great Plains species and the Virgin Valley forms are better known a final judgment on the specific determination of the Nevada species may best be postponed.

A lower jaw, no. 10655, with the milk molars and a portion of the first permanent molar in the process of eruption was referred tentatively to *H. equinus* (Scott) by Gidley.[15] As this specimen was represented principally by the lower milk dentition which had not been known before, an exact comparison with the known

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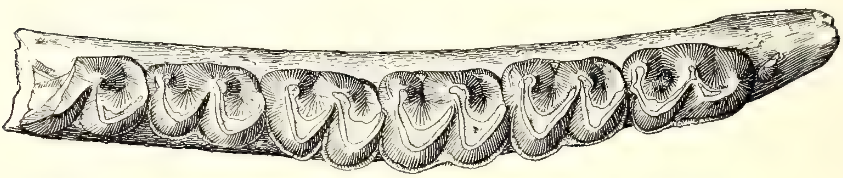
[14] Gidley, J. W., Notes on a Small Collection of Fossil Mammals from Virgin Valley, Nevada, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, pp. 235–246, 1908.

[15] *Op. cit.,* p. 236.

species was very difficult. As shown by Gidley the lower milk molars of *Hypohippus,* as represented by this form, are distinguished from those of *Mesohippus* by the heavier and better developed external basal cingula, the protoconid and hypoconid being fuller and wider transversely, and the teeth more specialized in general. Especially is the advanced development noticable in lower milk molar two in *Hypohippus* "in which the anterior external cusp has attained a completely crescentic form similar to that of the posterior cusp, while in *Mesohippus* this tooth has but one crescent, or V, the posterior one."

M_1, the only permanent tooth represented in specimen 10665, described by Gidley, is slightly larger than the teeth of *H. equinus* and is a little smaller than in *H. affinis.* It is of almost



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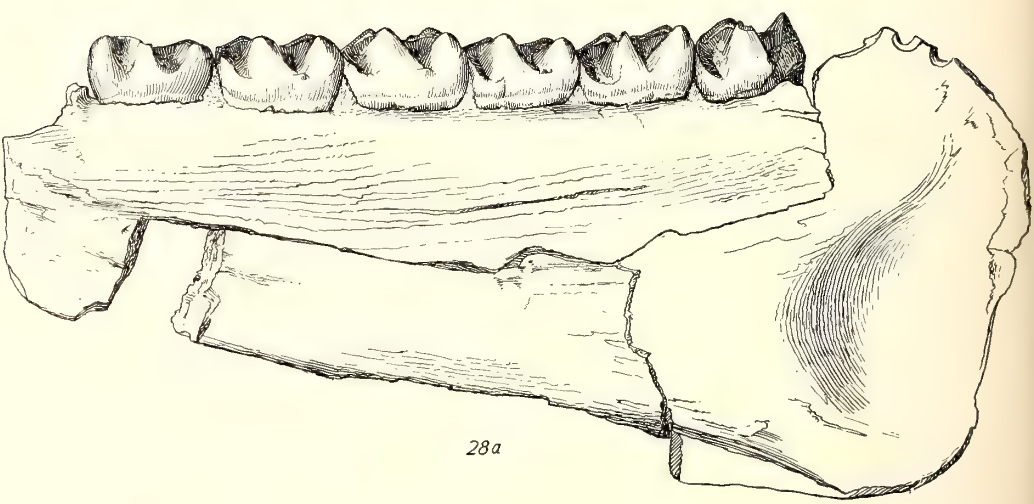


28a

Figs. 28*a* and 28*b*. *Hypohippus,* near *osborni* Gidley. Lower jaw with dentition. No. 12587, × ¾. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 28*a,* outer side; fig. 28*b,* superior view.

exactly the same size, according to the figure, as that of an unnamed species of *Hypohippus* described by Gidley[16] from the Loup Fork of South Dakota.

The permanent inferior cheek-tooth dentition of a species of *Hypohippus* apparently identical with the form described by Gidley is exhibited in several specimens. A lower jaw (no. 12587, figs. 28*a* and 28*b*) shows all of the lower molars and premolars perfectly preserved excepting a small portion of M_3 and P_1. A series of three perfectly preserved teeth (no. 11760, figs. 26 and 27), found together, represent molars one to three of another individual.

In general the teeth of specimen 12587 resemble the inferior series of *H. equinus* as figured and described by Scott. They differ in their relatively greater width and in the smaller size of P_1. The posterior region of the median internal, or metaconid, pillars is not distinctly angular as in *H. equinus* as figured by Scott. This difference may be due in part to wear. On P_3, P_4, and M_1 a very small tubercle appears on the inner side between the metaconid and entoconid. In M_1 and M_2 there is no suggestion of a groove separating a metastylid from the metaconid. There is in fact no distinct metastylid present. The external cingulum is quite strongly developed.

The three molars comprising no. 11760 show apparently the same dimensions as no. 12587. The posterior region of the metaconid is distinctly angular as in *H. equinus,* the hypostylid is a little more prominent than in no. 12587 and the small tubercle is not present between the inner borders of the metaconid and entoconid. Though distinguished by the slight difference just mentioned it is hardly probable that these two forms are specifically separable.

A well preserved upper molar one or two (no. 11570, fig. 25) represents a form of *Hypohippus* in which the teeth appear to be relatively somewhat narrower anteroposteriorly than in *H. equinus,* and in this respect approach the type of *H. osborni.*

An upper molar specimen (no. 12564, fig. 24) is apparently identical in size with M_3 of *H. osborni.* The abruptness of the

[16] Gidley, J. W., Bull. Amer. Mus. Nat. Hist., vol. 22, p. 136, 1906.

walls surrounding the impressed areas on the outer side of the paracone and metacone is so different from the much more gently curving lines of the outer side of tooth no. 11570 as to suggest that the two teeth represent different species; they may, however, belong to the same form.

From such evidence as is available it seems probable that none of the specimens of *Hypohippus* from the Virgin Valley region are identical with *H. equinus* though, as suggested by Gidley, the difference is very slight. The upper molar represented in no. 12564 is apparently near to *H. osborni,* but not actually identical with it. The lower molars of series no. 11760 differ quite distinctly from *H. equinus* in width and in the smaller size of P_1. According to the measurements which Dr. W. D. Matthew has kindly furnished, the lower molars of *H. osborni* show relatively greater width than in *H. equinus,* as in the upper molars. The lower molars of the Virgin Valley forms are somewhat larger but especally wider than those of *H. equinus.* They are somewhat smaller than the corresponding teeth of the type specimen of *H. osborni,* but approach this form a little more closely than to *H. equinus.*

MEASUREMENTS

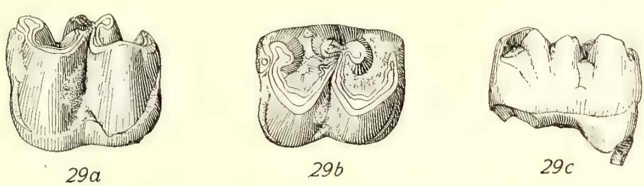
	*H. osborni**	*H. equinus*	*H. affinis*	No. 12587	No. 11570	No. 12564
P^3, anteroposterior diameter	25.7 mm.	25				
P^3, transverse diameter	28.7	27				
P^4, anteroposterior diameter	27.	25				
P^4, transverse diameter	29.9	26				
M^1, anteroposterior diameter	27.2	25				
M^1, transverse diameter	31.	28				
M^2, anteroposterior diameter	23.3	25			23.1	
M^2, transverse diameter	31.5	27			28.6	
M^3, anteroposterior diameter	21.	21				21.
M^3, transverse diameter	27.8	22				27.2
Length of inferior premolar series	76.5	78		72.		
P_1, anteroposterior diameter	8.5	13		7.4?		
P_1, transverse diameter	6.2	6				
P_2, anteroposterior diameter	24.2	21		22.8		
P_2, transverse diameter	14.5	9		14.5		
P_3, anteroposterior diameter	23.9	22	28.	22.7		
P_3, transverse diameter	17.4	13	20.	17.7		

* The dimensions of the inferior dentition were kindly furnished by Dr. W. D. Matthew.

	H. osborni	*H. equinus*	*H. affinis*	No. 12587	No. 11760	No. 10665
P_4, anteroposterior diameter	24.	22	27.5	23.		
P_4, transverse diameter	19.4	14	21.	18.6		
M_1, anteroposterior diameter	23.8	23	28.5	22.	22.2	
M_1, transverse diameter	18.1	14	20.	16.	16.5	15.8
M_2, anteroposterior diameter	23.5	22		21.	21.8	
M_2, transverse diameter	16.2	12		14.4	15.4	
M_3, anteroposterior diameter	26.3	25			25.	
M_3, transverse diameter	15.	10		13.	13.2	

PARAHIPPUS, compare AVUS (Marsh)

Several lower cheek teeth from Virgin Valley (figs. 29*a* to 29*c*) represent a species of *Parahippus* larger than *Parahippus crenidens* of the Deep River Beds or *P. brevidens* of the Mascall, but corresponding approximately in size to *P. nebrascensis* described by Peterson[17] from the upper Harrison Beds. This species should be compared with the doubtful *Parahippus avus* (Marsh) from the Mascall.



Figs. 29*a* to 29*c*. *Parahippus*, compare *avus* (Marsh). No. 19403, natural size. Fig. 29*a*, outer view; fig. 29*b*, occlusal view; fig. 29*c*, inner view. Virgin Valley Beds, Virgin Valley, Nevada.

The crowns of the lower cheek teeth are short and the enamel is quite rough. On all of the specimens there is evidence of a considerable covering of cement. On the outer side there is a distinct shelf developed on the cingulum, and a small basal tubercle is present between the protoconid and hypoconid. The metaconid and metastylid pillars are distinctly separated. The entoconid pillar is also large and the entostylid is well developed. The development of the metaconid, metastylid, and entoconid pillars tends to narrow the inner ends of the anterior and posterior valleys much more than in *Hypohippus*. A characteristic

[17] Peterson, O. A., Ann. Carneg. Mus., vol. 4, p. 57, 1906.

feature of all of these specimens is seen in a small but distinctly developed fold on the posterior side of the ridge of the hypoconid extending toward the metastylid.

This form is evidently the least common of the Virgin Valley horses, *Merychippus* having been the most abundant, and *Hypohippus* more common than *Parahippus*.

Occurence: Virgin Valley Beds; localities 1090 and 1095; Virgin Valley, Humboldt County, Nevada.

Measurements

Inferior cheek tooth, P_4?

Anteroposterior diameter of crown	20.5 mm.
Greatest transverse diameter of crown	16.7
Height of slightly worn crown, measured at metaconid	11.9

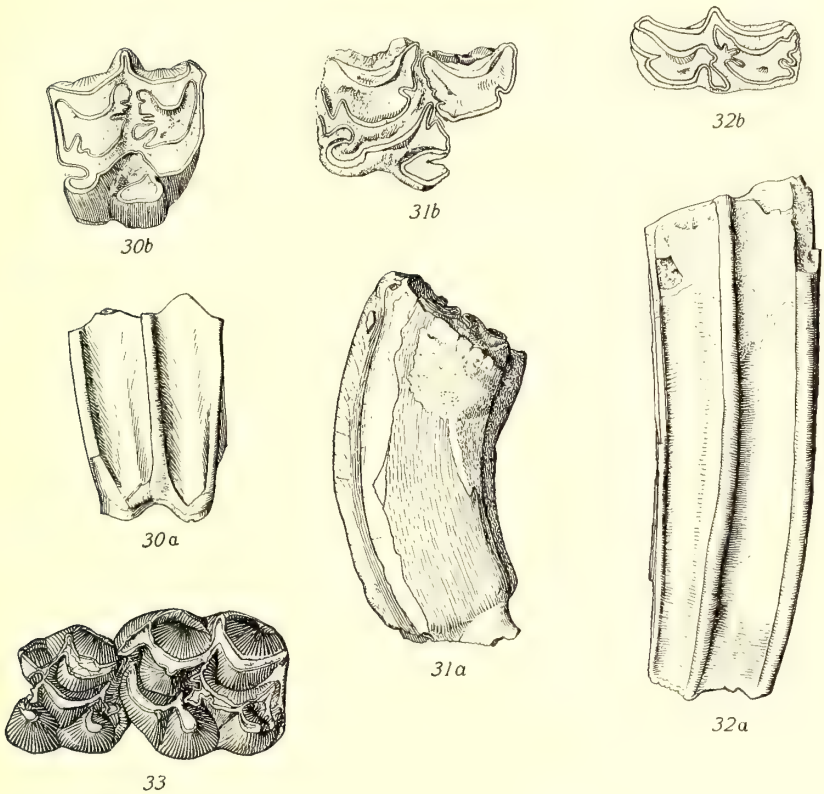
MERYCHIPPUS, near ISONESUS (Cope)

Teeth of *Merychippus* are the most common remains of fossil horses in Virgin Valley, where they occur in association with those of *Hypohippus*. They are found also at High Rock Cañon, farther to the south, but have not been seen in the beds at Thousand Creek.

In the collections obtained at Virgin Valley in 1906 Gidley[18] has recognized four forms of *Merychippus* teeth. These included a form referred provisionally to *Merychippus isonesus* (Cope), a second species (Gidley, species indet. 1) considered as possibly representing a new form of *Merychippus* with *Protohippus* affinities, a third (Gidley, species indet. 2) which was compared with *Merychippus seversus* (Cope), and a fourth (Gidley, species indet. 3) represented by a comparatively higher and straighter crowned form than the others.

In the larger collections now available from Virgin Valley the several forms present do not appear to represent any types other than those referred to by Gidley. Unfortunately the material nearly all consists of scattered teeth, excepting a few fragments of lower jaws with teeth. As the lower teeth are not associated with the upper dentition it is not possible to determine with certainty their relation to the forms described by Gidley,

[18] Gidley, J. W., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 238, 1908.

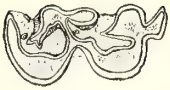


Figs. 30*a* and 30*b*. *Merychippus*, near *isonesus* (Cope). No. 11862, natural size. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 30*a*, occlusal view; fig. 30*b*, outer view.

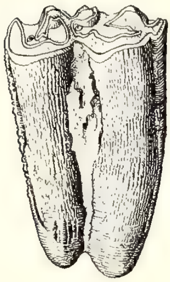
Figs. 31*a* and 31*b*. *Pliohippus*(?), sp. Superior molar. No. 12582, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 31*a*, posterior side; fig. 31*b*, occlusal view.

Figs. 32*a* and 32*b*. *Equus*(?), sp.; or *Neohipparion*(?), sp. Superior molar. No. 12581, natural size. Thousand Creek Beds(?), Thousand Creek, Nevada. Fig. 32*a*, outer side; fig. 32*b*, occlusal view.

Fig. 33. *Merychippus*, sp. Superior milk molars. No. 19412, natural size. Soldier Meadows, Humboldt County, Nevada.



34b



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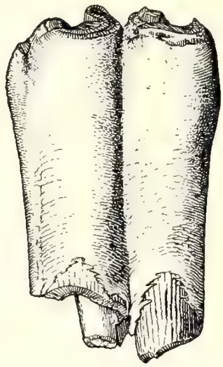

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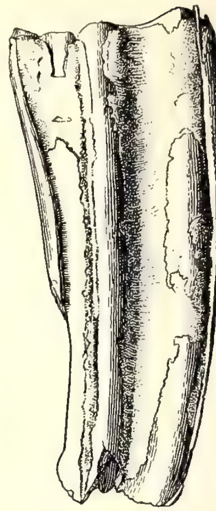

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Figs. 34*a* and 34*b*. *Merychippus*, near *isonesus* (Cope). Inferior cheek tooth. No. 11690, natural size. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 34*a*, outer side; fig. 34*b*, occlusal view.

Fig. 35. *Pliohippus* (?), sp. Inferior molar. No. 19413, outer side, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 36. *Equus* (?), sp. Inferior molar. No. 19414, outer side, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

which were all represented by upper teeth. Taking into consideration the variability of hypsodont molar teeth of horses, it does not seem advisable to attempt a definite characterization of the species of *Merychippus* from the Virgin Valley region until some of the several forms present in this fauna are represented by more complete material than is now available.

Teeth of the forms referred to *M. isonesus* (Cope) (figs. 30*a*, 30*b*, 34*a*, and 34*b*) are the most common remains of Equidae in the Virgin Valley Beds.

Occurence: Virgin Valley Beds at Virgin Valley and High Rock Cañon, Humboldt County, Nevada.

MERYCHIPPUS, near SEVERSUS (Cope)

A small form of *Merychippus* approximating the type of *M. seversus* (Cope) appears rarely in the beds at Virgin Valley, and

is represented by several specimens occuring at High Rock Cañon in association with a larger *Merychippus* and a species of *Hypohippus*.

Occurrence: Virgin Valley Beds at Virgin Valley and at High Rock Cañon, Humboldt County, Nevada.

PLIOHIPPUS(?), sp.

At several localities in the Thousand Creek region remains were found representing an equine form much larger than the *Merychippus* species of Virgin Valley. The heavily cemented upper molars are in most of the specimens (figs. 31*a* and 31*b*) a little shorter than in typical species of *Equus*, and show the strong curvature of *Pliohippus*. The wide enamel lakes show a moderate degree of plication. These teeth correspond in general with the type which is recognized by Gidley and by Matthew as *Pliohippus*. It would not however be entirely safe to refer them certainly to this group until more complete material is available. They may certainly be included within the limits of *Pliohippus* and *Protohippus* taken together.

The pattern of the enamel presents peculiarities which may distinguish this form from other described species, but with the fragmentary material available it is not advisable to do more than characterize the type found here as apparently slightly different from the known species.

Remains of the *Pliohippus* type are the characteristic representatives of the Equidae in the Thousand Creek Beds.

EQUUS(?), sp.

At some of the localities at which teeth referred to *Pliohippus*(?) were collected a number of larger equine molars (figs. 32*a*, 32*b*, and 36) have been found in which the characters approach those of *Equus*. The crowns are longer and straighter and the fossets are relatively narrower transversely than in the specimens referred to *Pliohippus*. The character of the enamel folds on the posterior side of the prefossette and the anterior side of the postfossette is different from those in the forms referred to *Pliohippus*. In most of the characters in which these teeth differ from the specimens referred to *Pliohippus* they ap-

proach *Equus*. Relationship to *Neohipparion* can not be disproved, as the protocone region is not preserved in any of the specimens. The presence of a number of large, heavy astragali of the *Equus* type in the Thousand Creek region lends some support to the view that the large molar teeth represent that genus. It is also possible that these forms represent an *Equus* derived from a terrace formation of Pleistocene age which has possibly been laid down over the Thousand Creek Beds. In some of the localities at which these specimens were found there is distinct evidence of terracing, but no deposits have been recognized which are distinguishable from the Thousand Creek Beds into which the terraces are cut.

RHINOCEROTIDAE

Numerous scattered remains of rhinoceroses were found both at Virgin Valley and at Thousand Creek. The specimens consist mainly of loose foot-bones, with a few teeth and parts of jaws. None of the specimens seem to the writer to be definitely determinable.

APHELOPS(?), sp.

A last upper molar and a portion of a lower jaw with the dentition (figs. 37 and 38), and several astragali from Virgin Valley are tentatively referred to *Aphelops*.

37

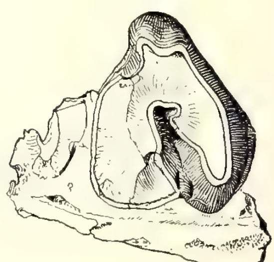

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Fig. 37. *Aphelops*(?), sp. Fragment of inferior mandible with dentition. No. 11607, × ¼. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 38. *Aphelops*(?), sp. M^3. No. 11672, × ½. Virgin Valley Beds, Virgin Valley, Nevada.

TELEOCERAS(?), sp.

In the Thousand Creek Beds many scattered limb-bones of rhinoceroses were obtained, but no teeth appear in the collections from these beds. From the limb elements, particularly the metapodials and the astragali, it is evident that the common rhinoceroses of Thousand Creek are different from the common forms of Virgin Valley, and evidently represent a form near *Teleoceras*. It is not improbable that more than one form is represented at Thousand Creek.

CHALICOTHERIDAE

MOROPUS(?), sp.

Remains of chalicotheres have been obtained at the lower fossil-bearing horizon in Virgin Valley, and associated with a similar fauna at High Rock Cañon. Thus far no remains of representatives of this family have been seen in the collections from the upper fossiliferous horizons at Virgin Valley or from any of the localities in the Thousand Creek region.

The specimens obtained include a few teeth and a considerable number of foot-bones, which closely resemble the forms referred to *Moropus* Marsh.

The teeth present include a representation of both the upper and lower cheek-tooth series. A lower molar, no. 12595 (figs. 40*a* and 40*b*) is complete excepting for the loss of the most anterior


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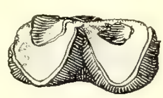
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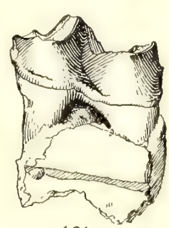

40b

Figs. 39 to 40*b*. *Moropus*(?), sp.

Fig. 39. P^4. No. 12596, × ½. Virgin Valley Beds, Virgin Valley, Nevada.

Figs. 40*a* and 40*b*. Inferior molar, M_2?. No. 12595, × ½. Virgin Valley Beds, High Rock Cañon, Nevada. Fig. 40*a*, occlusal view; fig. 40*b*, lateral view.

portion of the parastylid ridge. Although considerably worn the form of this tooth suggests that of M_2 in *Macrotherium grande.* On the outer side of the tooth there is a well-marked shelf connecting the trigonid and talonid portions. On the outer side of the protoconid a slight ridge is developed on the cingulum. On the corresponding region of the hypoconid the surface is smooth. Behind the hypoconid region there is a prominent shelf which slopes upward toward the distal end of the entoconid region.

MEASUREMENTS OF LOWER MOLAR, M_2?, NO. 12595

Greatest anteroposterior diameter	40.2 mm.
Greatest transverse diameter	19.4
Anterior posterior diameter of heel	22.3

In an upper cheek-tooth, no. 12596 (fig. 39), evidently representing P_4, the ectoloph is comparatively simple as in *Moropus elatus.* The deuterocone is transversely compressed, while the anterior and posterior ends of this cusp are connected with the outer ridge. A deep pit or valley is formed between the outer and inner ridges as in *Moropus elatus*, but the inner cusp seems a little less like a simple crescent than in the corresponding tooth of that species as figured by Peterson.[19]

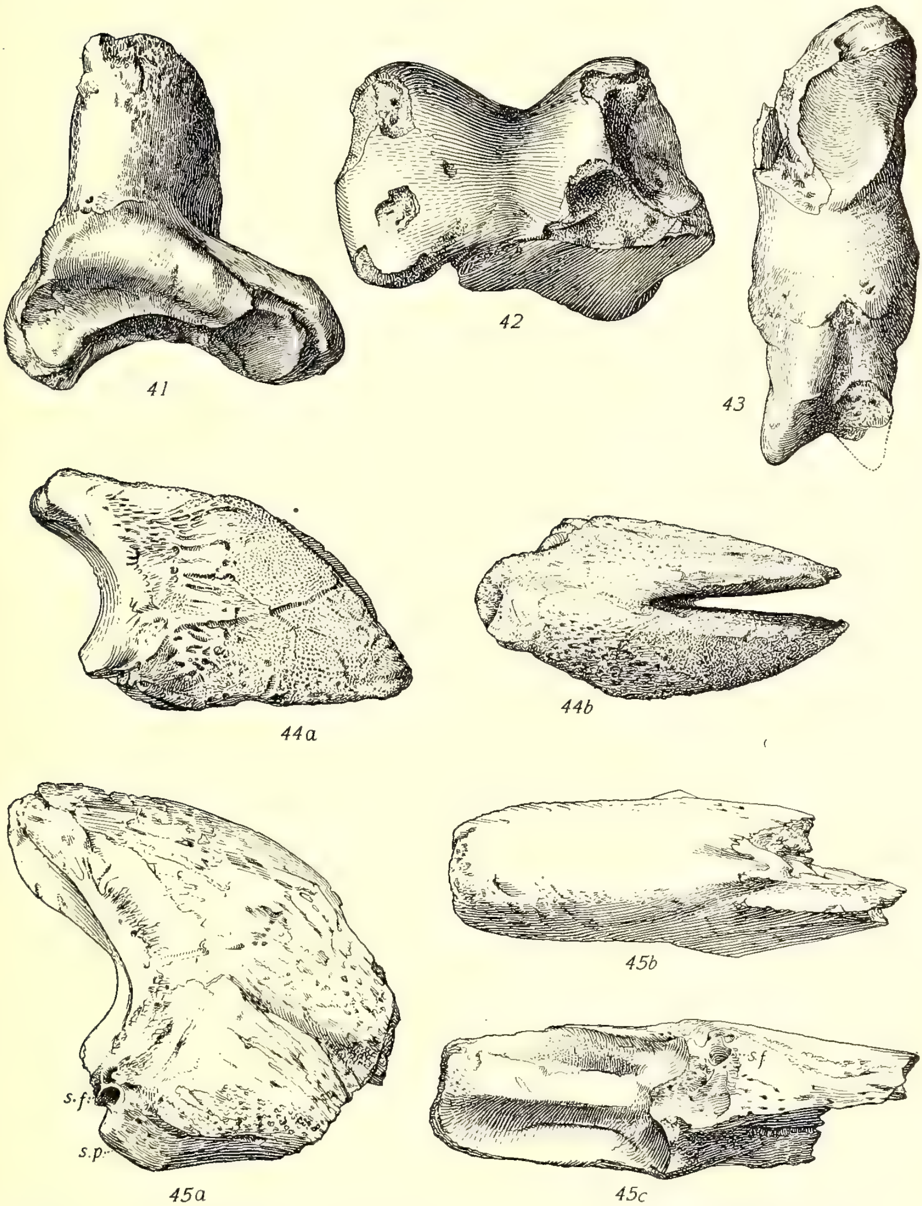
MEASUREMENTS OF P^4, NO. 12596

Greatest transverse diameter	26.3 mm.
Greatest anteroposterior diameter	20.2

Of the limb elements twelve phalangeal bones have been found in Virgin Valley and at Little High Rock Cañon. They evidently represent both the fore and hind limbs. Two or three specimens are apparently proximal phalanges not united with the second phalange. One specimen, no. 19406 (fig. 43), shows the union of the first and second phalanges. This bone is relatively large and is much more compressed laterally than the other specimens. It corresponds in form and size with the largest terminal phalange present, and both probably belong to digit two of the anterior limb. No specimens representing phalange two were found that were not co-ossified with the proximal element.

A very large terminal phalange (no. 19407) from Little High Rock Cañon (figs. 45*a* to 45*c*) evidently represents digit two of

[19] Peterson, O. A., Amer. Natur., vol. 41, p. 741, fig. 25, 1907.



Figs. 41 to 45*c*. *Moropus* (?), various species. × ½. Virgin Valley Beds. Fig. 41, High Rock Cañon. Figs. 42 to 44, Virgin Valley. Figs. 45*a* to 45*c*, Little High Rock Cañon.

Fig. 41. Calcaneum, superior view. No. 19405. Posterior end incomplete.

Fig. 42. Astragalus, superior view. No. 19404.

Fig. 43. Fused phalanges 1 and 2, superior view. No. 19406.

Figs. 44*a* and 44*b*. Terminal phalange. No. 10723. Fig. 44*a*, lateral view; fig. 44*b*, superior view.

Figs. 45*a*, 45*b*, and 45*c*. Terminal phalange. No. 19407. Fig. 45*a*, lateral view; fig. 45*b*, superior view; fig. 45*c*, inferior view; *s.f.*, subungual foramen; *s.p.*, subungual process.

the anterior limb. It is high and narrow with a deep terminal cleft. A large subungual process is developed, and a large foramen is present on the posterior-lateral angle of the process which remains entire. The nature of the subungual process and of the accompanying foramen suggests very strongly the characters of the corresponding region in the terminal phalanges of the gravigrade edentates. The deep terminal cleft and the entire absence of any indication of a hood around the basal region of the claw show that this form is a chalicothere and not a gravigrade.

A somewhat similar but smaller and less compressed claw from Virgin Valley shows the subungual process less developed. There is in this specimen a large foramen on one side of the basal process, and a much smaller one on the opposite side. The character of the inferior region of the claw in these specimens is not unlike that of the specimen of *Macrotherium grande* figured by Deperet,[20], though the subungual process appears to be somewhat deeper in the specimen from Little High Rock Cañon.

A third claw (no. 10723) from Virgin Valley (figs. 44*a* and 44*b*) is relatively shorter and thicker and the cleft is deeper. The subungual process is scarcely developed and the basal foramina are small. This claw is possibly from the posterior limb. It was associated with the astragalus and calcaneum.

The astragalus, no. 19404 (fig. 42), is very short, being sharply truncated anterior to the trochlea, so that there is no neck. The anterior articular surface shows no distinct articular facet for the cuboid. The trochlear surface is broad and the groove fairly deep.

In the calcaneum, no. 19405 (fig. 41) the sustentacular region is very prominent, though the sustentacular face for articulation with the astragalus is not extraordinarily large. The external face for articulation with the astragalus extends forward almost to the anterior end of the bone. It also reaches inward to join the sustentacular face, so that the interosseous ligament did not separate them.

With the material available one does not seem to be justified

[20] Deperet, C., Arch. Mus. Lyon, t. 5, pl. 4, fig. 7*a*, 1892.

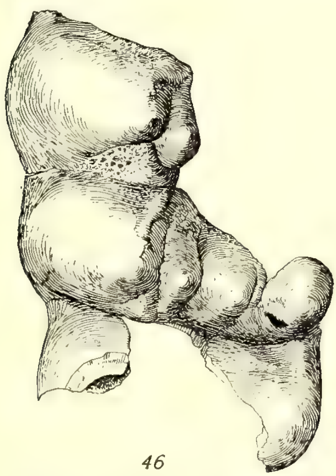
in definitely referring the Virgin Valley chalicotheres to any of the known species. Especially is this difficult owing to the fragmentary nature of the types of the species, *M. distans* and *M. senex*, described by Marsh from the John Day region, which is separated by only a short distance from Virgin Valley. The Virgin Valley form is presumably very near if not identical with some of the forms already described. If some of the material from the John Day region should prove to have been derived from the Mascall formation there would be reason to suspect that the Virgin Valley species is nearly related to it. If all of the material from the John Day Valley is from the John Day formation specific identity is improbable.

Occurrence: Virgin Valley Beds. localities 1065 and 1095, Virgin Valley, Humboldt County, Nevada; also from High Rock Cañon and Little High Rock Cañon, Humboldt County, Nevada.

PROBOSCIDEA

MASTODON (TETRABELODON ?, sp.)

Remains of proboscideans were found frequently both at Thousand Creek and Virgin Valley. In Virgin Valley they were obtained in the highest horizons in which fossil remains were seen, and also occurred well down in the section, though possibly not at the lowest horizon at which collections were made.



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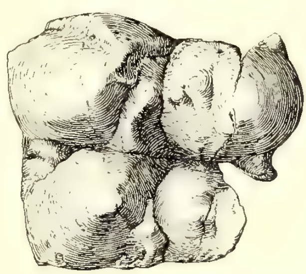

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Figs. 46 and 47. Mastodon (*Tetrabelodon* ?, sp.). Portions of cheek teeth. No. 19445, × ½. Virgin Valley Beds, High Rock Cañon, Nevada.

The Virgin Valley specimens comprise a number of scattered limb-bones, and several cheek teeth with a small part of a tusk. All of this material represents a form of the mastodon type, but the specimens are not perfect enough to permit an exact determination. The size of the tooth fragments indicates that the individuals were quite large. A few fragments associated with a specimen found low down in the section at Virgin Valley seem to show an enamel band along the side of a tusk. A series of almost unworn teeth which had broken down and scattered over many square yards of a steep hillside in the Virgin Valley Beds of High Rock Cañon was partly recovered and pieced together, so that a portion of the form of the molars can be represented in figures 46 and 47.

In the Thousand Creek Beds proboscidean remains are not uncommon, though nearly always scattered or badly fractured. A proboscidean jaw with a portion of the skull (pl. 33) found by Miss Alexander in the beds at Thousand Creek was the only specimen obtained that represented more than an isolated element of the skeleton. This skull had evidently been broken before it was buried, and the part remaining had been unevenly preserved. The teeth and a portion of the jaw were preserved without alteration, though intersected by very numerous fractures. The remaining part of the skull had broken down to a soft pulpy mass which could not be satisfactorily preserved. The dentition of this specimen seems to be of a fairly advanced type, and may represent a tetralophodont form. Other material from the Thousand Creek Beds evidently represents the same form as the specimen found by Miss Alexander.

SUIDAE

PROSTHENNOPS(?), sp.

A number of associated bones and teeth (no. 11876) from Thousand Creek represent a large dicotyline form probably most nearly allied to *Prosthennops.* No exact comparison with the species of that genus can be made as the parts present in the Nevada material are not well preserved in the available *Prosthennops* material.

Maxillary of Mastodon (*Tetrabelodon?*, sp.) in place. Thousand Creek Beds, Thousand Creek, Nevada.

Two upper premolars are present. The smaller one (*a*, fig. 53) is nearly triangular in cross-section. It supports a large external and a slightly swollen internal tubercle. There is a minute median anterior tubercle, but otherwise the cingulum is not well developed on the anterior side of the tooth. On the posterior border there is a well-developed transverse shelf. This tooth is less advanced than P^2 of *Tayassu* in that it possesses but a single tubercle on the outer border.

The other premolar (*b*, fig. 53) is nearly quadrate in cross-section. The tubercles of the anterior pair are nearly equal. The postero-external tubercle or tritocone is slightly smaller than the protocone. In the postero-internal angle three tubercles are developed. The anterior of these three may represent the tetartocone, the other two belonging to the posterior shelf of the cingulum. This tooth corresponds in development approximately to P^3 of *Tayassu*. The posterior-internal tubercle is smaller than in that form, but the tooth as a whole comes as near the quadrate form as P^3 of *Tayassu*.

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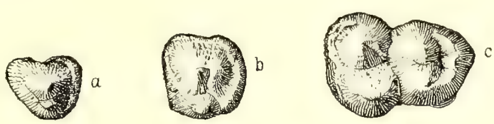

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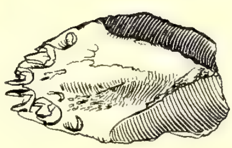

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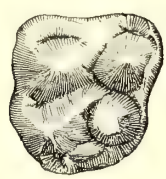


55

Figs. 52 to 53*a*. *Prosthennops*(?), sp. No. 11876. Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 52. Inferior canine, × ½.

Fig. 53*a*, P^2?, natural size. Fig. 53*b*, P^3 or P^4, tooth tilted slightly toward inner side in the figure, natural size. Fig. 53*c*, M^3, natural size.

Fig. 54. Portion of mandible of a large suilline. No. 19416, × ½. Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 55. *Thinohyus*(?), sp. M^3. No. 11854, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

A single well-preserved premolar tooth almost identical in form and dimensions with the one just described was found connected with a fragment of the jaw at another locality in the Thousand Creek region. In this specimen the enamel is well preserved but the tubercles are slightly worn. The cingulum is well developed on the anterior side of the protocone and deuterocone, and on the outer side of the tritocone. The fragment of the maxillary shows immediately above the tooth a strongly-marked shoulder which formed the floor of the depression leading to the infraorbital foramen as in *Tayassu.* The small foramina anterior to the depression leading to the infraorbital foramen are immediately above the exposed posterior root of the tooth. Judging from the position of the infraorbital foramen in *Tayassu* and *Prosthennops,* unless the infraorbital foramen was here situated considerably farther back than in these forms, this tooth is possibly P^3 rather than P^4.

The smaller of the two premolars is evidently more advanced than the P^2 which must have occupied the very small alveolus for this tooth shown in the figure of *Prosthennops crassigenis* figured by Matthew and Gidley.[21]

The larger premolar has but three roots instead of four as in P^4 of *P. crassigenis,* but the quadrate form is as well developed as in that tooth.

Considering the smaller premolar as either P^2 or P^3 and the larger as either P^3 or P^4, and taking all of the combinations possible, the Thousand Creek species is less advanced than *Tayassu* or *Mylohyus,* but more advanced than *Platigonus.* A fully satisfactory comparison of this nature with *Prosthennops* is not possible. If the smaller tooth of the Thousand Creek specimen represent P^3, *Prosthennops crassigenis* is apparently more advanced. If this tooth is P^2, as seems possible from the situation of the larger premolar with reference to the infraorbital foramen, the stage of evolution of the premolars is approximately the same in the two forms or slightly more advanced in the Thousand Creek species. With the exception of possible differences in the

[21] Matthew, W. D., and Gidley, J. W., Bull. Amer. Mus. Nat. Hist., vol. 20, p. 266, fig. 14, 1904.

premolars, to which reference has just been made, the Thousand Creek specimen approaches *Prosthennops* more closely than to the other American genera of the Suidae.

The third upper molar (*c*, fig. 53) is the only molar preserved complete. The enamel is much corroded so that the tuberculation is not entirely clear, but the tooth appears to be of the dicotyline type. There is a small heel developed on the cingulum behind the hypocone and metacone. The dimensions of this tooth are near those in *Prosthennops crassigenis*.

A large lower canine (fig. 52) occurring with this individual is triangular in cross-section with a faintly expressed ridge on the middle of the outer face.

MEASUREMENTS

No. 11876

P^2, anteroposterior diameter	10. mm.
P^2, transverse diameter	8.4
P^3 anteroposterior diameter	11.2
P^3, transverse diameter	10.8
M^3, anteroposterior diameter	21.2
M^3, transverse diameter	15.3

No. 11884

P^3, anteroposterior diameter	10.6 mm.
P^3, transverse diameter	11.

Other remains accompanying this specimen include small portions of the skull, a calcaneum, and the distal portions of two metapodials. One of the metapodials shows a flattened lateral surface above the distal end, indicating close contact with the metapodial paired with it.

THINOHYUS(?), sp.

A large upper molar (no. 11854, fig. 55) from Virgin Valley shows considerable resemblance to the form of M^3 in *Thinohyus* occurring in the John Day Beds. The greatest transverse diameter nearly equals the anteroposterior, as in M^2, but the posterior region is narrower than the anterior, and the posterior shelf on the cingulum is more prominent than on any of the molars excepting M^3.

This tooth represents a large species, presumably belonging in the hyotherine division of the Suidae rather than in the later and more specialized dicotylines.

MEASUREMENTS, M^3?. No. 11854

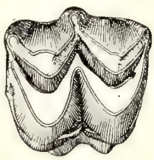
Greatest anteroposterior diameter	21. mm.
Greatest transverse diameter	20.2

OREODONTIDAE

MERYCHYUS(?), sp.

Two molar teeth from Virgin Valley furnish the only evidence of oreodonts from the deposits of this region.

One specimen, no. 12606 (fig. 48), is an upper molar two. This tooth is very near the stage of devolopment of *Eporeodon,* but the crown tends to be slightly more hypsodont and the mesostyle more sharply narrowed anteroposteriorly. At the point where



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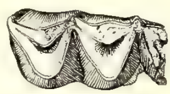


49

Fig. 48. *Merychyus,* sp. M^2. No. 12606, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

Fig. 49. *Merychyus,* sp. M_3. No. 11825, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

the horns of the hypocone and protocone crescents are united, the posterior horn of the protocone crescent is a little wider than the anterior horn of the hypocone crescent.

There is only a suggestion of ribs on the outer side of the paracone and metacone. The cingulum is well developed on the anterior side of the protocone crescent, and between the protocone and hypocone. It extends around the inner border of the protocone as a faint ridge. The cingulum is interrupted on the inner side of the hypocone, but is represented by a weak shelf on the posterior side of the hypocone crescent. Faint shelves are present on the cingulum of the outer side of the paracone and metacone.

A lower molar three, no. 11825 (fig. 49), shows a weak median style and only faint indications of ribs on the middle of the inner side of the two inner crescents. A shelf is developed on the cingulum only on the anterior side of the tooth. The pos-

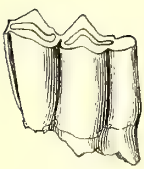
terior lobe is largely broken away, but enough of it is present to indicate that it was large, and the inner face seems not to have turned very far outward and backward away from the plane of the inner side of the anterior portion of the tooth.

Measurements

M^2, anteroposterior diameter measured on outer side	19.2 mm.
M^2, transverse diameter measured at base across protocone	18.1
M_3, anteroposterior diameter along metaconid and entoconid crescents, measured on inner side	18.8
M_3, transverse diameter measured across protoconid and metaconid crescents	11.4

CAMELIDAE

Numerous fragmentary remains of representatives of the Camelidae were found in the exposures at Thousand Creek, and somewhat less abundantly at Virgin Valley. Unfortunately the material that has been obtained consists only of scattered bones with small fragments of the skull and a few teeth. The foot-bones represented show a considerable range in size, and indicate the presence of at least two forms at Thousand Creek, and two at Virgin Valley. One of the species at Thousand Creek included



50a

50b

51

Figs. 50*a* and 50*b*. Camel, compare *Camelus americanus* Wortman. M_3. No. 12765, $\times \frac{1}{2}$. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 50*a*, lateral view; fig. 50*b*, occlusal view.

Fig. 51. Cameloid. Premaxillary and portion of maxillary. No. 19416, $\times \frac{1}{4}$. Thousand Creek Beds, Thousand Creek, Nevada.

individuals of very large size, probably representing *Pliauchenia.* At Virgin Valley there was also a large form and a much smaller species. With the scattered limb elements available it is not possible to make a definite determination of any of the forms represented.

Judging from the quantity of camel remains seen, these animals must have been very common in the fauna of this region during the deposition of the Thousand Creek Beds, and also formed an important part of the Virgin Valley fauna.

An isolated third lower molar, no. 12765 (figs. 50*a* and 50*b*), from Thousand Creek represents a form that resembles *Auchenia* in the presence of a prominent buttress or pillar on the anteroexternal angle of the tooth. This buttress is also well-marked in *Camelus americanus* described by Wortman[22] from the Pleistocene of Hay Springs. The anteroexternal buttress is possibly a little stronger than in *C. americanus,* but is not as well developed as in *Auchenia lama.* The dimensions of the tooth from Thousand Creek are greater than in the type of *C. americanus.*

MEASUREMENTS

No. 12765

M_3 anteroposterior diameter	35.9 mm.
M_3, transverse diameter across protoconid	12.5
C. americanus, Hay Springs	
M_3, anteroposterior diameter estimated from figure published by Wortman	29 mm.

A portion of a skull comprising the premaxillaries and a part of the maxillaries from Thousand Creek (fig. 51) represents a camel about as large as the existing *Camelus bactrianus.* The posterior ends of the premaxillaries are truncated on both sides in such a way as to suggest that they were covered by the anterior ends of the nasals. I^1 and I^2 are absent, P^1 was large. At a distance behind P^1, which exceeds slightly the distance between the canine and P^1, there is a small alveolus for a premolar which is presumably P^2.

CERVIDAE

BLASTOMERYX MOLLIS, n. sp.

Type specimen no. 11564, Univ. Calif. Col. Vert. Palae. from

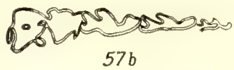
[22] Wortman, J. L., Bull. Am. Mus. Nat. Hist., vol. 10, p. 133, 1898.

lower Virgin Valley Beds, Virgin Valley, Nevada. Cotype no. 11567 from the same locality.

Several jaws and teeth from Virgin Valley and High Rock Cañon represent a species of *Blastomeryx* differing only slightly from *B. primus* and *B. olcotti* from the Upper Rosebud Beds of South Dakota. The tooth row is slightly longer than in either *B. primus* or *B. olcotti.* P_1 is not represented. On one speci-

56b

56a



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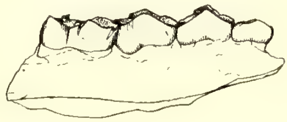

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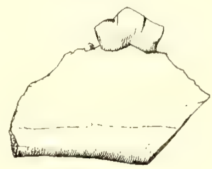


58a

Figs. 56*a* and 56*b*. *Blastomeryx mollis,* n. sp. M_3. No. 11565, natural size. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 56*a*, lateral view; fig. 56*b*, occlusal view.

Figs. 57*a* and 57*b*. *Blastomeryx mollis,* n. sp. Fragment of mandible with inferior dentition. No. 11567, natural size. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 57*a*, lateral view; fig. 57*b*, occlusal side.

Figs. 58*a* and 58*b*. *Blastomeryx mollis,* n. sp. Fragment of jaw with P_3 and alveolus of P_2. No. 12609, natural size. Virgin Valley Beds, High Rock Cañon, Nevada. Fig. 58*a*, inner side of jaw fragment with P_3; fig. 58*b*, occlusal view of P_3.

men from Virgin Valley (no. 11567, figs. 57*a* and 57*b*) a space half the anteroposterior diameter of P_2 is present immediately in front of that tooth but without an alveolus for P_1, so that if P_1 was present it was not situated close to P_2 as in *B. olcotti.* On a specimen from High Rock Cañon (no. 12609, figs. 58*a* and 58*b*) a still larger space anterior to P_2 shows no alveolus for P_1. P_3 and P_4 are triangular in cross-section as in *B. olcotti* and have otherwise much the same form as in that species.

In the slightly greater length of the tooth row, relatively larger size of the premolars or smaller size of M_3 and absence of P_1 immediately anterior to P_2 the Nevada form differs from *B. olcotti.* From *B. primus* it differs in the triangular rather than oval form of P_4, in a slightly longer tooth row, and probably in the anteroposterior diameter of the premolars.

The stage of advance of this species is close to that of *B. primus* and *B. olcotti,* and it may possibly be united with one of these forms when more material is available for study.

MEASUREMENTS

	No. 11565	No. 10661	No. 11567	No. 11566	No. 12609	No. 11564
Length, anterior side P_2 to posterior side M_1			31.3 mm.			
P_2, anteroposterior diameter			5.4			
P_3, anteroposterior diameter			7.8		8.5	7.8
P_4, anteroposterior diameter		8.9	9.1	8.5	8.8	8.8
M_1, anteroposterior diameter		9.	9.2	9.5	8.8	8.5
M_2, anteroposterior diameter				10.3	10.	9.8
M_3, anteroposterior diameter	13.8					13.
M_3, transverse diameter						7.3
Length, anterior side P_3 to posterior side M_3						45.5
Height of mandible below P_2					14.3	
Height of mandible below M_2					14.9	14.2

DROMOMERYX, sp. *a*, near BOREALIS (Cope)

Several jaws and teeth from Virgin Valley correspond very closely to forms which have been referred to *Palaeomeryx,* and have recently been designated as a new genus, *Dromomeryx,* by Douglass.[23]

A single upper molar, described and figured by Gidley[24] was referred by him tentatively to *Palaeomeryx* (?) *borealis.*

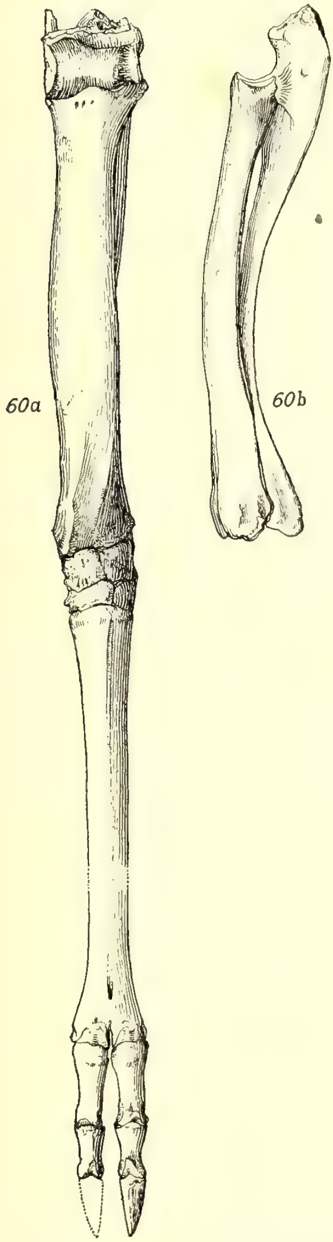
Several fragments of jaws with teeth, and a lower molar, M_3 (fig. 62), belong to an animal about as large as that represented by the upper molar described by Gidley. On specimen no. 12601 the palaeomeryx fold is well marked on M_1, and is faintly shown on M_2. The basal tubercle between the protoconid and hypoconid is large. There is a distinct anterior basal ridge as in the specimens from Snake Creek recently referred to *Palaeomeryx* by Matthew and Cook.[25]

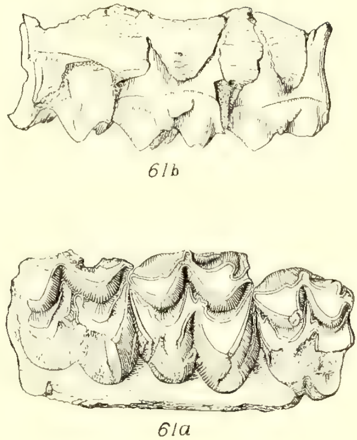
The anteroposterior dimension of M_3 is near that of the *Palaeomeryx* species from Snake Creek. On this tooth the palaeomeryx fold is only suggested, the basal tubercle between

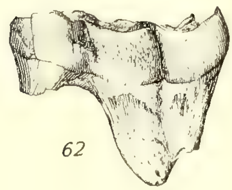
[23] Douglass, Earl, Ann. Carneg. Mus., vol. 5, p. 461, 1909.

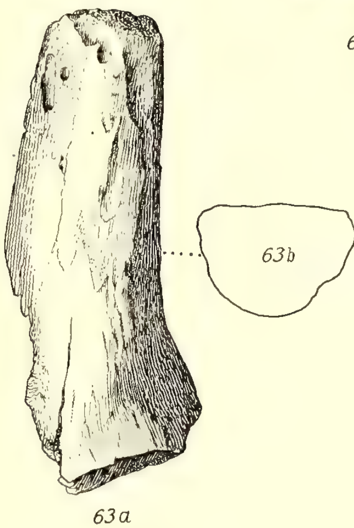
[24] Gidley, J. W., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 241, 1908.

[25] Matthew, W. D., and Cook, H. J., Bull. Am. Mus. Nat. Hist., vol. 26, p. 408, 1909.









Figs. 60*a* and 60*b*. *Dromomeryx*, sp. *a*, near *borealis* (Cope). Anterior limb. No. 19417, × ¼. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 60*a*, anterior view of limb; fig. 60*b*, lateral view of radius and ulna.

Figs. 61*a* and 61*b*. *Dromomeryx*, sp. *b*. Superior molar series. No. 11470, natural size. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 61*a*, occlusal view; fig. 61*b*, outer view.

Fig. 62. *Dromomeryx*, sp. *a*, near *borealis* (Cope). M_3. No. 11748, natural size. Virgin Valley Beds, Virgin Valley, Nevada.

Figs. 63*a* and 63*b*. *Dromomeryx*, sp. Basal region of horn. No. 11628, × ½. Virgin Valley Beds, Virgin Valley, Nevada. Fig. 63*a*, outer side; fig. 63*b*, cross-section.

the protoconid and hypoconid is large, and there is a faint basal tubercle between the hypoconid and the heel.

Numerous scattered limb elements from the Virgin Valley Beds represent a form of *Dromomeryx* near *borealis* (Cope). The best preserved specimen is one from locality 1095, in which the larger part of an anterior limb is represented. In this specimen the proportions of the limb differ slightly from those given by Douglass for *D. borealis.* This is especially true of the metapodial. In the limb figured (fig. 60*a*) a section of the middle of the bone was missing when the specimen was discovered. Without considering the missing fragment the length of this bone is greater and the form more slender than that of the anterior metapodial figured by Douglass. Making a small allowance for this fragment the length of the Virgin Valley specimen is noticeably greater and the slenderness more apparent.

Measurements

No. 19417	
Radius.	
Greatest length along anterior border	250. mm.
Greatest diameter across distal end	47.6
Digit IV.	
Phalange I, greatest length	45.5
Phalange II, greatest length	29.
Phalange III, greatest length	39.5
No. 10676	
M^3, anteroposterior diameter	19.6
No. 19444	
Upper molar, anteroposterior diameter	21.2
No. 11748	
M_3, anteroposterior diameter	30.

DROMOMERYX, sp. *b*

A portion of an upper jaw with molars 1 to 3 (no. 11470, figs. 61*a* and 61*b*) is from a form referable to *Dromomeryx,* but considerably smaller than the specimen examined by Gidley. This specimen represents an individual quite certainly distinct from *D. borealis* (Cope). On the upper molars of this specimen there is a prominent shelf developed upon the cingulum on the outer wall of the paracone in a situation in which no similar

shelf appears on the figured specimens which the writer finds referred to *Palaeomeryx* or *Dromomeryx*.

The shelf on the cingulum is strongest next the mesostyle, and disappears opposite the middle of the outer side of the paracone. A similar shelf appears to be shown on the larger form described by Gidley, but it seems to the writer to be due in some part at least to a fracture of the specimen. On two other upper molars of the larger form from Virgin Valley there is no suggestion of this shelf.

The possibility that the first two of the upper molars of no. 11470 described above represent the milk dentition has been considered, but the evidence does not seem to indicate that this is the case. Even if this were true, it should be noted that the shelf of the cingulum described above is shown on the most posterior tooth, as well as on the others, and would still be a characteristic of the permanent dentition.

A shelf of the type seen in the smaller form is barely suggested on a large worn specimen of *Dromomeryx* from the Mascall Beds of Oregon.

MEASUREMENTS

No. 11470

Length, anterior side M^1 to posterior side M^3	44.3 mm.
M^1, anteroposterior diameter	14.3
M^1, transverse diameter	18.5
M^2, anteroposterior diameter	16.0
M^2, transverse diameter	20.3
M^3, anteroposterior diameter	15.8
M^3, transverse diameter	19.0

DROMOMERYX, sp.

In the collections from Virgin Valley there is a specimen consisting of the basal portion of a large horn-core, no. 11628 (figs. 63*a* and 63*b*), the form of which shows close resemblance to *Dromomeryx*. The portion of the horn present is nearly straight, with only a suggestion of curvature, and narrows gradually from the base upward. The basal portion of the core is triangular in cross-section. The section of the terminal region seems to have been approximately oval. The texture of the surface of the core is in general more dense or less pitted than in *Aplocerus*.

Though it is not possible to make a definite determination of the affinities of the form represented by this specimen, it is probable that it represents a large, antelope-like type similar to *Dromomeryx.*

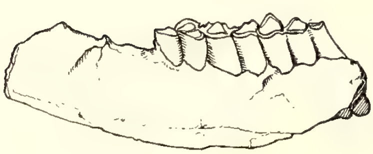
ANTILOCAPRIDAE

MERYCODUS, near FURCATUS (Leidy)

The genus *Merycodus* is represented by a number of antlers (fig. 66) from Virgin Valley. The best preserved antler from Virgin Valley extends upward to a height of 110 mm. above the base without branching. The middle of the burr is 25 mm. above the base. It seems to resemble *M. furcatus* most nearly, though the several specimens of antlers known average a little smaller than *M. furcatus*, and the burr is a little higher.

64

66



65

Fig. 64. *Merycodus nevadensis,* n. sp. (?). Basal region of horn. No. 12524, × ½. High Rock Cañon, Humboldt County, Nevada.

Fig. 65. *Merycodus nevadensis,* n. sp. Portion of lower jaw with dentition. No. 12608, type specimen, natural size. High Rock Cañon, Humboldt County, Nevada.

Fig. 66. *Merycodus,* near *furcatus* (Leidy). Basal region of horn. No. 11319, × ½. Virgin Valley Beds, Virgin Valley, Nevada.

MERYCODUS NEVADENSIS, n. sp.

Type a lower jaw with M_1 to M_3, no. 12608, Univ. Calif. Col. Vert. Palae. from High Rock Cañon, Nevada. A slender antler from the same locality.

Lower cheek-tooth series less than 45 mm. in length. M_1 to M_3 inclusive 25 mm. Molars distinctly hypsodont, considerably compressed laterally, M_3 with small heel.

The lower jaw fragment (fig. 65) from High Rock

Cañon shows little of the form of the mandible, excepting its height below the premolars. The molar teeth are the only ones present, but a liberal estimate of the length of the cheek-tooth series from P_2 to M_3 indicates that this form was considerably smaller than *M. furcatus, M. necatus,* and *M. osborni.* The molars are distinctly hypsodont, without styles between the outer pillars, and are rather sharply compressed. On M_3 the heel is a little smaller than the middle segment of the tooth.

MEASUREMENTS, NO. 12608

Approximate height of mandible below P_2	11.2 mm.
Length, M_1 to M_3 inclusive	25.3
M_1, anteroposterior diameter	6.8
M_1, transverse diameter of posterior segment	3.8
M_2, anteroposterior diameter	7.6
M_3, anteroposterior diameter	11.5
M_3, transverse diameter of middle segment	3.7

An antler obtained at High Rock Cañon (fig. 64) is slender, slightly swollen a short distance above the base, and without traces of a burr. Like the lower jaw fragment, the antler is smaller than in *M. furcatus,* but may represent a young animal. It is considerably compressed in a plane inclined about 45° away from the anteroposterior plane of symmetry of the skull, and shows a distinctly marked concavity at the base of the horn immediately behind the orbit. So far as can be determined there seems reason for suspecting that the antler of the form represented by this specimen was not at any stage entirely similar to those of the previously described forms.

This form seems to differ so far from the known species as to make a specific correlation with any of them inadvisable, and the name *Merycodus nevadensis* is tentatively applied to it.

SPHENOPHALUS NEVADANUS Merriam

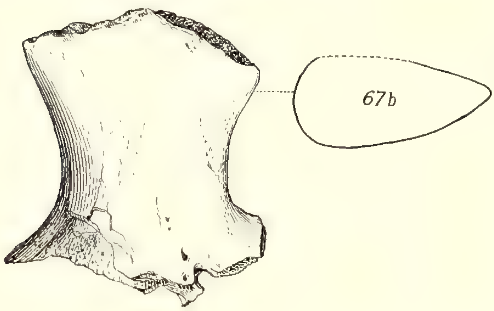
S. nevadanus Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 325, 1909.

This species was based on a number of specimens representing portions of the skull with horn-cones. In the original description it was characterized as follows:

"Frontals not cavernous at the base of the horns. Horns situated on the upper posterior region of the orbits, sloping backward, slightly out

ward, and tilted upward at an angle between twenty-five and thirty degrees from the plane of the frontals above the orbits. Horn-cores flattened in a plane extending backward and inward from the orbits. A short distance above the base the horn-cores flare or widen slightly in the direction of greatest diameter in cross-section. Outer anterior edge of the horn-core arising over the upper posterior region of the orbit, and swinging backward with a suggestion of a twist. Surface of the horn-core comparatively smooth, with a few pits or irregularities. Texture of the outer portion of the horn-core solid. Supraorbital formamina present in front of the middle of the antero-medial side of the base of the horn-cores.''

Horn-core.—In the collections which have been examined since the original description of this species a number of fragmentary specimens have been obtained which represent this form. One of these, no. 12537, represents the base of a horn-core (figs. 67*a* and 67*b*), which is wider anteroposteriorly, but much thinner transversely than the type specimen. It also differs somewhat from the type in the nature of the region on the posterior side of the base of the horn-core. In the type-specimen, this region is very broadly rounded or nearly flat transversely. In no. 12537 the posterior basal region is relatively much narrower, and a low longitudinal keel is developed on the middle of the posterior surface.



Figs. 67*a* and 67*b*. *Sphenophalos nevadanus* Merriam. Basal region of horn. No. 12537, × ½. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 67*a*, medial side of horn; fig. 67*b*, cross-section of horn.

In this specimen the tendency of the horn-core to flare anteroposteriorly a short distance above the base is more distinctly shown than in the type material. This is possibly due in part to the slightly better preservation of the anterior margin in this specimen. Though the differences between this specimen and the type of *S. nevadanus* are considerable, it quite certainly represents the same general group and may be referred to this species.

In the thinness of the horn and in the tendency to develop a

low median ridge on the surface of the narrower posterior side of the horn-core, this specimen approaches the modern *Antilocapra* a little more closely than does the type material. As nearly as can be determined from the fragmentary specimen, the other characters which separate the type of *Sphenophalos* from *Antilocapra* are as marked here as in the type specimen.

Measurements of the Horn-Cores

	Pronghorn No. 8298*	No. 11887	No. 11888	No. 12537
Anteroposterior diameter at narrowest point above the base	41.3 mm.	41.7	36.5	44.8
Greatest anteroposterior diameter	50.	51.5	43.	60.
Transverse diameter measured ured at the same point as the least anteroposterior diameter	23.9	33.	28.4	27.

* Calif. Mus. Vert. Zool.

Dentition.—In the collections thus far obtained in the Thousand Creek region there are quite a number of long-rooted molar-teeth of antelope-like forms that show a considerable range in size. Some of the specimens represent animals as large as the existing *Antilocapra*, others come from much smaller forms. It is probable that some of these teeth represent *Sphenophalos nevadanus.* All of the cheek-teeth of antelopes from the Thousand Creek region are closely similar in form and structure to those of the Recent *Antilocapra.* Some of the larger teeth which seem most appropriate in size to accompany the skull of *Sphenophalos* are noticeably similar in form to the corresponding teeth of *Antilocapra.*

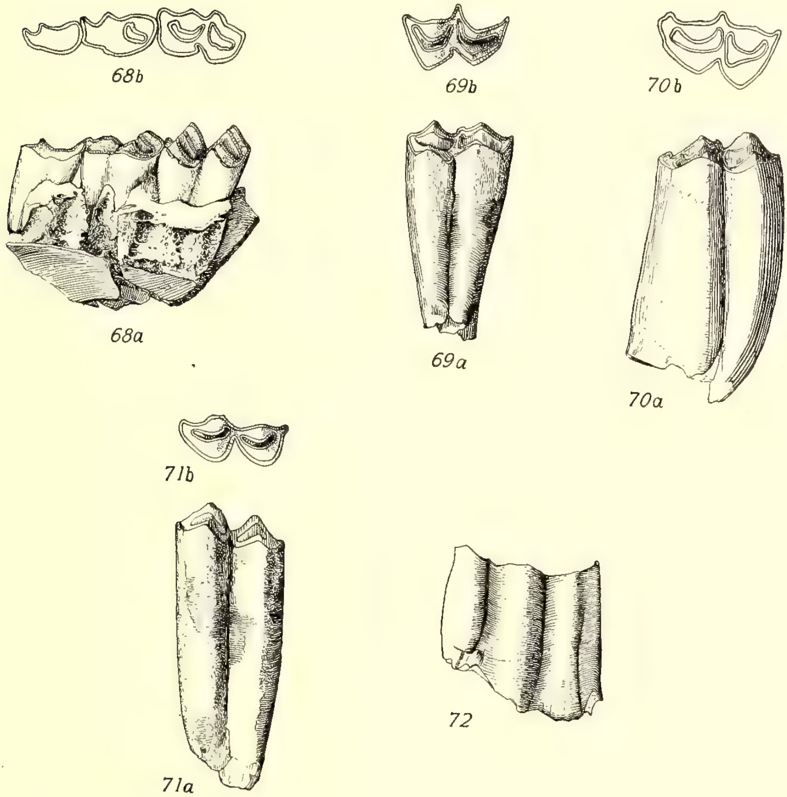
The upper and lower molars are all long-rooted, reaching almost, if not quite, to the stage of development of the Recent *Antilocapra* in this particular.

Two upper molars from Thousand Creek resemble the corresponding teeth of the Recent *Antilocapra* in form and size. A third upper molar, no. 12610 (figs. 70*a* and 70*b*), is similar to M_3 of *Antilocapra.* It differs mainly in the shortness of the wing or lobe developed on the posterior side of the tooth. A hypsodont lower molar M_2, no. 12604 (figs. 71*a* and 71*b*), has the same anteroposterior diameter as M_2 of *Antilocapra,* but is

noticeably narrower transversely. These teeth may presumably be referred to *Sphenophalos.* They probably represent the type species, *S. nevadanus,* which was represented by individuals fully as large as the living pronghorns of the Nevada region.

From one place at locality no. 1100 a considerable number of fragments of teeth were found which include a number of pieces of upper molars like those referred tentatively to *Sphenophalos,* and with these an interesting fragment representing the wall of a third lower molar. This specimen (fig. 72) shows a tooth comparable in size to M_3 in *Antilocapra,* but differing from that form in the nature of the third or posterior lobe. In *Antilocapra* the posterior lobe is normally sharply divided into two pillars by a deep vertical groove in the outer wall. In *Capromeryx* this groove is apparently barely indicated near the lower end of the tooth, and in *Merycodus* it is unrepresented. The specimen from Thousand Creek is distinctly different from the existing *Antilocapra* in that the external longitudinal groove on the posterior lobe, though clearly shown, marks only a weak separation compared with the sharply-marked constriction in *Antilocapra.*[26] This tooth is presumably to be referred to

[26] In one of two specimens of *Antilocapra* available from northern Nevada there is a notable exception to the type of M_3 normal in this form. In this specimen (no. 8299 Univ. Calif. Mus. Vert. Zool.) the permanent molars are present, and the last milk premolar is just on the point of dropping out. In both rami M_3 is a three-lobed tooth, but the posterior lobe shows no indication of a division into two parts by a longitudinal external groove. The posterior lobe in this specimen is about as large as the portion of the posterior lobe anterior to the external longitudinal groove in the typical specimens. No suggestion of an external longitudinal groove is present, even low down on the tooth. The writer is not entirely clear as to the significance of this variation of M_3. If this character should appear in other specimens, and at the same time be coupled with other variations from the normal type, it might have some claim to importance as a specific distinction. In this specimen the peculiar character of M_3 is accompanied by an apparent slight modification of the character of the posterior side of M^3 and by a weaker development of the external styles of the upper molars. The deviation of the upper molars from the type of tooth shown in other specimens available may be due in part to difference in degree of wear, but this factor does not seem competent to account for the whole difference. Unless more material of the same nature as this specimen comes to hand, one would hardly seem justified in considering the variation shown here as more than an individual abnormality. Even if classed as an individual peculiarity, it may be found to have some significance in the interpretation of the history of variation or differentiation in this group, but our knowledge of the meaning of such irregularities in the growth of individuals is yet too imperfect to give us a clue as to the interpretation of this case.



Figs. 68*a* and 68*b*. *Sphenophalos* or *Ilingoceros*, sp. P^3 to M^1. No. 12613, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 68*a*, inner view; fig. 68*b*, occlusal view.

Figs. 69*a* and 69*b*. *Sphenophalos* or *Ilingoceros*, sp. Upper molar. No. 12605, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 69*a*, outer view; fig. 69*b*, occlusal view.

Fig. 70*a* and 70*b*. *Sphenophalos nevadanus* Merriam(?). M^3. No. 12610, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 70*a*, inner view; fig. 70*b*, occlusal view.

Figs. 71*a* and 71*b*. *Sphenophalos* or *Ilingoceros*. Inferior molar. No. 12604, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 71*a*, outer view; fig. 71*b*, occlusal view.

Fig. 72. *Sphenophalos nevadanus* Merriam(?). Outer side of M_3. No. 19418, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

Sphenophalos, though it may represent the twisted-horned form *Ilingoceros*. It shows a stage of evolution tending toward the *Antilocapra* type, but a little less advanced than in that genus.

Measurement of Teeth of Antelope-Like Forms Referred in Part to Sphenophalos

			Capromeryx	*Antilocapra*
M_1, anteroposterior diameter			9.3 mm.	12.7
M_1, transverse diameter			5.1	6.7
M_2, anteroposterior diameter	No. 12604	14.7	11.0	14.7
	No. 12612	13.		
M_2, transverse diameter	No. 12604	6.9		7.7
	No. 12612	6.2		
M_3, anteroposterior diameter			16.5	24.
M_3, transverse diameter			5.6	8.
M^1, anteroposterior diameter	No. 12613	12.1		13.5
	No. 12603	11.7		
M^1, transverse diameter	No. 12613	8.4		10.1
	No. 12603	9.		
M^2, anteroposterior diameter	No. 12605	14.		15.4
M^2, transverse diameter	No. 12605	8.5		10.3
M^3, anteroposterior diameter	No. 12611	17.5*a*		17.
	No. 12610	17.		
M^3, transverse diameter	No. 12611	10.5		10.1
	No. 12610	10.3		
Anterior side P^3 to posterior side M^1	No. 12613	30.8		31.5
P^3, anteroposterior diameter		8.4		10.
P^3, transverse diameter		4.8		6.
P^4, anteroposterior diameter		10.4		10.2
P^4, transverse diameter		6.7		7.5
M^1, anteroposterior diameter		12.1		13.5
M^1, transverse diameter		8.4		10.1

a, approximate.

Relationships.—As was noted in the original description of *Sphenophalos*[27] this form resembles the prong-horn antelopes somewhat in the general form of the horn-core and also in the surface of the core. The tendency of the horn-cores of the fossil form to widen anteroposteriorly a short distance above the base is also a character in which they resemble the horns of the prong-horn. The horn-cores differ from those of the pronghorn in greater thickness, more oblique position, slightly more posterior situation, and entirely different topography of the postero-basal region.

Unfortunately we have not been able to obtain material showing the nature of the terminal region of the horns of *Sphenophalos.* The widening of the laterally compressed horn-core not far above the base certainly suggests that the terminal region may have a general resemblance to that of *Antilocapra.*

Of the large Antilocapra-like molar teeth found in the Thousand Creek Beds it seems probable that some of the specimens represent *Sphenophalos.*

Unfortunately the material representing the limbs, arches, and vertebral column of antelope-like forms found in these beds consisted solely of scattered bones, and nothing like a connected skeleton has been recovered. It is, however, well worth considering that none of this material represents forms which differ greatly from *Antilocapra,* and the larger forms are uniformly close to that genus.

Taking into consideration all of the evidence obtained from an examination of the skull material which can be definitely referred to *Sphenophalos,* and with it such evidence as is obtained from examination of the associated remains representing other parts of the skeleton and the dentition, there seems to be much in favor of the view that *Sphenophalos* is a representative of the Antilocapridae, while almost no facts present themselves which seems to contradict this hypothesis.

The difference between the Thousand Creek species and the Recent *Antilocapra* seems to the writer sufficient to require their generic separation, but it would not be surprising to find the

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27 Merriam, J. C., *op. cit.*, p. 328, 1909.

general relationship fairly close when better specimens of *Sphenophalos* become available.

ILINGOCEROS SCHIZOCERAS, n. sp.

Type specimen a complete horn-core, no. 11893, Univ. Calif. Col. Vert. Palae. From the Thousand Creek Beds at Thousand Creek, Humboldt County, Nevada.

In the first description of the genus *Ilingoceros,* two types of horn-cores of uncertain specific position were referred to this group as forms B and C. The specimen on which form C was based lacked the distal portion of the horn-core, as was shown in figure six of the original publication.[28] Since this paper was issued the terminal portion of this horn-core has been found in a small collection made only a few yards from the spot at which the type of form C was collected. The two fractured faces fit together perfectly and there is no possible doubt as to their representing the same horn-core.

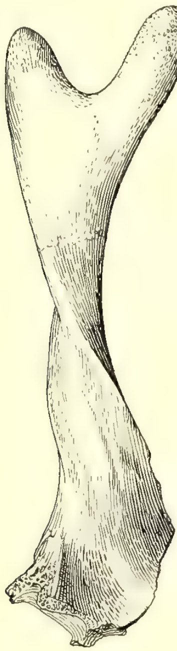
Horn-Core.—As shown in figures 73*a* and 73*b,* the portion now added to the original specimen carries the horn upward with the same spiral twist and flattened cross-section shown in the lower portion already described. The upper end of the horn, instead of narrowing to a point as in typical antelopes, is widened slightly and is deeply notched so that it ends in two distinct prongs. The terminations of the prongs are obtuse, and consist of much more spongy tissue than the rest of the horn.

The type of horn shown here is quite distinct from that of any form previously described. While the basal portion resembles that of the strepsicerine antelopes, the terminal region suggests the divided horns of certain forms of *Merycodus.* There is no suggestion of a burr on the horn, and since the terminal portion of the core is slightly wider than the middle region a sheath horn could not have been shed without splitting.

If this horn-core represents a young animal, it may possibly belong to one of the forms referred to *Ilingoceros alexandrae.* It was, however, associated with numerous remains of evident adults of a form much smaller than *I. alexandrae.* Under the

[28] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 323, fig. 6, 1909.

circumstances one does not seem justified in arbitrarily referring it to *I. alexandrae*, as that form distinctly differs in several



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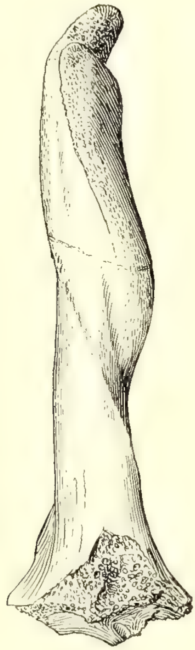

73b

Figs. 73*a* and 73*b*. *Ilingoceros schizoceras*, n. sp. Two views of the horn. No. 11893, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 73*a*, posterior side; fig. 73*b*, inner or medial side.

characters. In *I. alexandrae* the spiral ridge which has its origin on the postero-superior region of the orbit, arises anterior to the postorbital process of the frontal. In this form the ridge arising over the orbit is evidently continuous with the postorbital process. In *I. alexandrae* the horn is almost circular in cross-section; in this specimen the section is much flattened. Such fragments of horn-cores of *I. alexandrae* as are available indicate that the horns were considerably elongated, and round in section some distance above the base, having therefore quite a different character from those of this form.

For the present, one seems warranted in separating the type represented by specimen 11893 as a species distinct from *I. alex-*

andrae. It may be referred to the genus *Ilingoceros,* though it is not entirely certain that it is not also generically different.

The form of horn represented in this specimen suggests relationship with three groups, the Merycodontidae, the Antilopinae and the Antilocapridae. The resemblance to any known form of the *Merycodus* group is not close. The burr is entirely absent, the horn-core is strongly twisted, and the distal notching is very shallow. The shallowness of the notch might be expected in a young individual. There is, however, some reason for suspecting that this horn may represent a full grown animal, as it is associated with numerous remains of small antelope-like animals which are evidently adults. The horns of *Merycodus nevadensis* from the Virgin Valley Beds at High Rock Cañon present as near an approach to the antelope form as has been observed among forms referred to *Merycodus.*

The resemblance of this form to true antelopes of the strepsicerine type has already been commented upon in a former publication.[29] With only the portion of the horn below the tip represented a relationship to the tragelaphines is unavoidably suggested. Considered in connection with the other forms referred originally to the genus *Ilingoceros,* there seems good reason for inquiring whether this resemblance is not more than coincidence. There are no other horned forms in which the strepsicerine characters are developed, and the twisted-horned antelopes have been quite conspicuously represented in Tertiary time, their origin dating back at least to the Miocene period. Inasmuch as the antelope group has been presumed to be derived from forms near *Merycodus* it would not seem improbable that types like *I. schizoceras* should appear in the period of transition to the true strepsicerine forms, and possibly also in the young of early representatives of that group.

The resemblance of the horn-core of this form to that in *Antilocapra* consists largely in the general similarity of the surface structure. The form and position of the horn are not like those of the pronghorns, and the nature of the terminal region is also distinctly different. The fact that this horn-core is divided

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[29] Merriam, J. C., *op. cit.*

into two terminal prongs and that the outer or sheath portion of the horns of *Antilocapra* divides seems not to be a valid ground for comparison, as the horn-core in *Antilocapra* is not divided. That the horn-core of *Antilocapra* may have been divided originally, the anterior prong of the core afterward disappearing in that genus is possible, but we have as yet no evidence to show that such has been the actual course of evolution of the horn. If any relationship is suggested by the divided tip it would seem most natural to associate the form of horn seen here with the simpler types of *Merycodus*.

Associated Remains of Skeleton and Dentition.—Associated with the peculiar horn no. 11893, there are many parts of the skeleton and dentition representing several small antelope-like individuals. Although these parts have not been obtained in such association as to indicate that they certainly belong to *Ilingoceros schizoceras*, and they may be found to represent several species or genera, by process of exclusion they suggest certain possibilities as to the character of this species and of other antelope-like forms of this region.

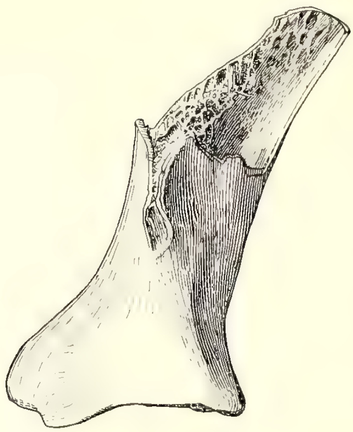
All of the fragments of *teeth* found associated with these remains represent hypsodont molars of about the same stage of advance as those of *Antilocapra*. The best preserved specimen in this collection is the outer wall of a third upper molar. The tooth is considerably smaller than in the specimens referred tentatively to *Sphenophalos*, and the outer styles are a little more prominent. The association of hypsodont molars of the *Antilocapra* type with the antelope-like remains from Thousand Creek has thus far been a rule without exception.

The *femur* is known by fragments representing the proximal and distal ends. The proximal portion of the articular surface of the head is elongated transversely about as in the pronghorn. The distal end does not differ essentially from that of the femur in the pronghorn.

The proximal end of the *tibia* differs from the pronghorn in the presence of a well-marked emargination in the overhanging border of the postero-internal portion of the proximal face. The proximal rudiment of the *fibula* is a little smaller than in the pronghorn specimen available for comparison. The distal end

is not appreciably different from that of *Antilocapra.* The upwardly projecting spine has about the same relative dimensions as in *Antilocapra.*

The *calcaneum* is similar to that of *Antilocapra.* At the posterior end of the internal ridge of the trochlea of the *astragalus* there is a noticeable prominence which extends downward and slightly inward over the sustentacular portion of the calcaneum.



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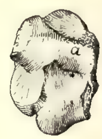

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77

74

Fig. 74. *Ilingoceros schizoceras,* n. sp.? Posterior metapodial. No. 19419, × ½. Thousand Creek Beds, Thousand Creek Nevada.

Figs. 75*a* and 75*b*. *Ilingoceros schizoceras,* n. sp. Proximal portion of scapula. No. 11892, natural size. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 75*a*, outer view; fig. 75*b*, proximal view.

Fig. 76. *Ilingoceros schizoceras,* n. sp.? Superior side of unciform; *a*, articulation with lunar. No. 19420, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 77. *Antilocapra americana* Ord. Superior side of unciform; a, articulation with lunar. No. 8299, Calif. Mus. Vert. Zool.; natural size.

The inner portion of the trochlea extends downward over this process instead of turning slightly forward beneath the astragalus as in *Antilocapra*.

In the *lunar* of the fossil form the hook which extends downward over the posterior side of the unciform is longer than in *Antilocapra*. Corresponding to this modification of the lunar there is a deep pit on the posterior side of the *unciform* immediately behind the face for contact with the lunar (figs. 76 and 77). The posterior hook of the lunar is received in this pit. In the unciform of *Antilocapra* there is only a shallow depression where the pit is situated in the fossil form, and the posterior portion of the articular face for the lunar is not continued downward as sharply as in the fossil form. The unciform also differs from that of *Antilocapra* in the development of a downwardly projecting process extending from the posterior side, immediately below the pit for the reception of the posterior hook of the lunar. In *Antilocapra* the posterior border is almost perfectly even in this region. There is shown here a tendency to develop a mere specialized interlocking joint in the wrist of the fossil form than is shown in *Antilocapra*.

The metatarsals (fig. 74) are not essentially different from those of *Antilocapra*. They vary considerably in size in different individuals. This bone in no. 11892 is relatively a little narrower than in *Antilocapra*.

The terminal *phalanges* of the fossil forms differ from those of *Antilocapra* in that they are a little sharper, or more distinctly pointed anteriorly, and the inferior foramen on the inner side of the posterior end is on the average of approximately the same size as the postero-superior foramen on the inner side, instead of being much smaller as in *Antilocapra*.

In the proximal end of a *scapula* (figs. 75*a* and 75*b*) available there is a slight difference from *Antilocapra* in the form of the coracoid process. In *Antilocapra* the process is wider transversely and is not separated from the external border of the glenoid cavity by a shallow notch as in the fossil form.

The proximal end of the *radius* is a little more extended on the outer side just outside of the proximal articular surface in *Antilocapra* than in the fossil form.

A broken *vertebra* from the posterior cervical region (5th?) seems to have larger zygapophyses than in the corresponding vertebra of *Antilocapra.* In a middle dorsal vertebra the zygapophysial faces are also relatively large, and the centrum is relatively low. Several lumbar vertebrae present in the collections have longer and lower centra than in *Antilocapra.* In one of these the spinal nerve passed through a foramen situated several millimeters in advance of the posterior margin of the neural arch.

ILINGOCEROS or SPHENOPHALOS

Several fragmentary specimens representing the dentition of antelope-like forms from Thousand Creek resemble those referred to *Sphenophalos* in most respects, but are smaller and may belong with some of the forms referred to *Ilingoceros.*

A portion of the upper jaw, no. 12613 (figs. 68*a* and 68*b*), with P^3 to M^1 represents an animal somewhat smaller than *Antilocapra* or than the teeth tentatively referred to *Sphenophalos nevadanus.* The teeth are apparently hypsodont, though considerably reduced by wear. M^1 is slightly narrower than in *Antilocapra* and the median rib on the outer side of the paracone is more prominent than in that form. P^4 is considerably narrower and apparently a little less advanced in the development of the crescents. The form represented by this jaw evidently belongs to a species distinct from that in which the larger teeth referred to *Sphenophalos nevadanus* are included. It may correspond to a smaller species of *Sphenophalos,* or may represent one of the species in the group of twisted-horned forms included in the genus *Ilingoceros.*

A smaller upper molar, no. 12605 (figs. 69*a* and 69*b*), and a lower molar, no. 12612, may be referred tentatively to the same group as the upper jaw fragment, no. 12613. They are both hypsodont, and resemble *Antilocapra* in most respects. The upper molar, no. 12605, is smaller anteroposteriorly and transversely than in *Antilocapra,* and possesses a minute style between the protocone and hypocone pillars. The lower molar, no. 12612, is shorter anteroposteriorly and considerably narrower than in *Antilocapra.* Both of these specimens evidently belong to a

form related to that represented by the larger teeth included in the species referred to *Sphenophalos nevadanus.*

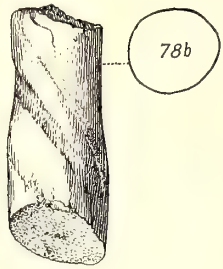
ILINGOCEROS ALEXANDRAE Merriam

Ilingoceros alexandrae Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 320, 1909. From the Thousand Creek Beds of Thousand Creek, Humboldt County, Nevada.

Affinities.—Since publishing the original description of this peculiar form, the collections from Thousand Creek have been carefully examined for material which might furnish additional information regarding its structure and affinities. Excepting such information as has been presented above under the discussion of *I. schizoceras,* nothing has appeared which suggests any modification of the original description. The only light which is thrown on the question of affinities of the genus *Ilingoceros* is developed through study of the other remains representing antelope forms obtained from the same formation. An examination of the remains associated with those of *Ilingoceros* in the formation at Thousand Creek does, however, offer certain suggestions which seem to demand consideration.

Thus far in the collections at Thousand Creek the specimens representing the dentition of antelope-like forms include only hypsodont molar teeth. No short-crowned teeth like those of *Tragelaphus* have been discovered. Also worthy of note is the general absence from the outer side of the lower molars of prominent styles or pillars such as appear between the columns of the short-crowned lower molars of *Tragelaphus* and *Strepsiceros.* In one or two specimens of molars from Thousand Creek small intermediate styles are seen, but they are very poorly developed.

When the first studies of the antelopes of the Nevada Tertiaries were being carried on the writer was aware of the presence of several forms of large molar teeth of antelope-like forms in the collections from Virgin Valley and Thousand Creek, but was not at that time able to make certain as to the association of the horns and teeth. Since the publication of the first paper it has been shown that all of the large molar teeth with basal intermediate styles were obtained from exposures in Virgin Valley, which represent a much lower horizon than those of Thou-



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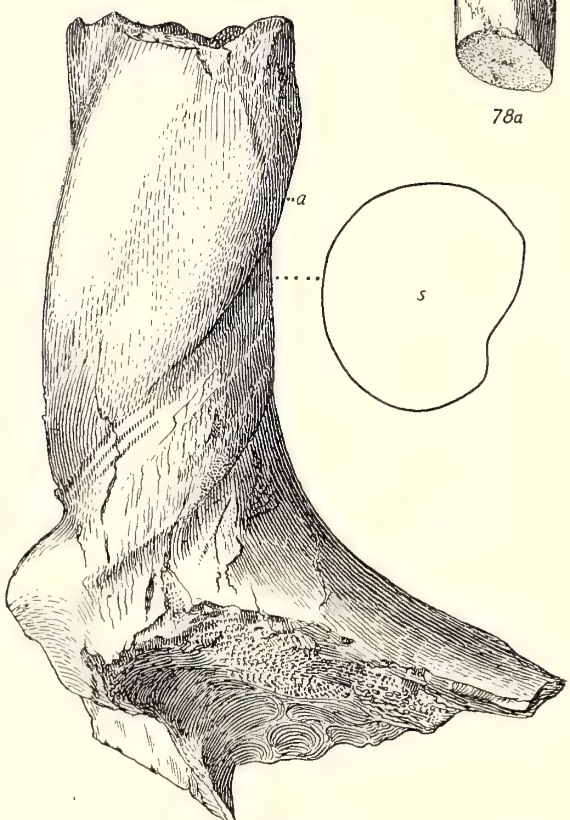

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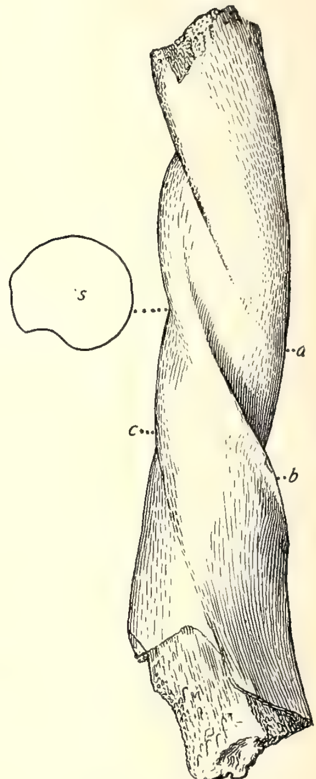

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Figs. 78*a* and 78*b*. *Ilingoceros alexandrae* Merriam. Fragment from the distal region of horn. No. 11886, × ½. Thousand Creek Beds, Thousand Creek, Nevada. Fig. 78*a*, lateral view showing spiral; fig. 78*b*, cross-section of horn.

Fig. 79. *Ilingoceros alexandrae* Merriam. Posterior view of base of left horn-core; *a*, spiral ridge arising over the postero-superior region of the orbit; *s*, cross-section of horn-core. No. 11880, type specimen, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

Fig. 80. *Ilingoceros*, form B. Posterior to postero-median view of basal portion of right horn-core; *a*, anterior spiral ridge probably corresponding to ridge *a* in figure 79; *b*, median or lateral spiral ridge; *c*, posterior spiral ridge; *s*, cross-section of horn-core. No. 11892, natural size. Thousand Creek Beds, Thousand Creek, Nevada.

sand Creek from which all of the twisted-horned forms were derived. All of the larger Virgin Valley specimens representing antelope-like forms are to be referred to *Dromomeryx* (*Palaeomeryx.*)

Some of the hypsodont molars from Thousand Creek presumably represent the forms included in the genus *Sphenophalos*, but one seems hardly justified in referring all of the specimens to that genus, inasmuch as not more than a third of the total number of skull fragments obtained belong to *Sphenophalos*, and in two instances horn-cores representing the twisted form were found in fairly close association with the long-crowned molars, while remains of *Sphenophalos* were absent.

It appears most reasonable to consider the probabilities in favor of associating some of the long-crowned molars with the skull fragments bearing twisted horns. Some of these teeth, as has been shown under the discussion of *Sphenophalos*, are evidently near the *Antilocapra* type, and none of them, so far as known, seem to differ greatly from those of that form. It is also true that such skeletal remains as are known seem to differ little in general character from the type of *Antilocapra*. Unfortunately, excepting the skulls, no skeletal parts of the tragelaphine antelopes are available to the writer for comparison with that group.

The indirect evidence of relationship suggested by the dentition indicates that the twisted-horned forms are related to *Sphenophalos* and, with that genus, to *Antilocapra*. The presumable relationship of *Sphenophalos* to *Antilocapra* has already been discussed. It seems, however, certain that *Ilingoceros* is generically quite distinct from *Sphenophalos* and, whatever the grade of relationship, *Ilingoceros* seems farther from *Antilocapra* than is *Sphenophalos*.

With the scanty evidence available, the characters in which *Ilingoceros* seems most distinctly connected with *Antilocapra* are the presumptive similarity in the dentition and the nature of the outer portion of the horn-core, which like that of *Sphenophalos* seems to be a little more dense than is common in the tragelaphine forms. Otherwise it is hard to find characters which are distinctively antilocaprine.

The discovery of the terminal portion of a twisted horn in the form described above as *Ilingoceros schizoceras* unexpectedly complicates the problem of the relationships of *Ilingoceros* through the addition of the character of terminal bifurcation to that of spiral twist. While it is by no means certain that the species referred to as *I. schizoceras* is generically identical with *I. alexandrae* the evidence suggests that the two are probably of common origin. The presence in *I. schizoceras* of a terminal bifurcation of the horn as in *Merycodus* lends some support to the theory that the Merycodontidae may be the ancestors of *Ilingoceros.*

In the present state of our knowledge there seem three hypotheses open to account for the presence of the twisted-horned antelopes in the Thousand Creek fauna: (1) They are typical Old World tragelaphines which came into America in late Miocene or early Pliocene time and developed long-crowned molar teeth. (2) They are tragelaphine forms which originated in America from Merycodus-like ancestors at some time during the Miocene, and soon migrated to the Old World, leaving only a few descendants here as late as the Thousand Creek epoch. (3) They are a peculiar twisted-horned division of the Antilocapridae originating in America and possibly limited to this continent.

On the whole, the writer is inclined to think that the evidence favors recognition of a fairly close relationship of *Ilingoceros* as well as *Sphenophalos* with the Antilocapridae, and that all of these forms may be derived from some member of the *Merycodus* group. With the evidence at hand, one does not seem justified in assuming that the Old World tragelaphines are necessarily derived from American Merycodus-like ancestors, though both may have come from the same stock. There seem to be some reasons for thinking that the older tragelaphines of the Old World may have been derived from some form like *Palaeomeryx* or *Dromomeryx* rather than from a Merycodus-like type. *Dromomeryx* of the American Miocene possesses antelope-like horns and a dentition which might have developed into the tooth type found in the more primitive of the true antelopes.

In addition to the evidence suggesting the presence in

America of Old World types of antelopes as presented by the Thousand Creek fauna, Matthew and Cook[30] have recently described a peculiar antelopine or bovine horn-core, and an antelope-like dentition, from the late Tertiary beds of Snake Creek, Nebraska. As noted by Matthew and Cook, the dentition resembles that of the twisted-horned forms and not that of the type of antelope represented by the horn-core which has been provisionally associated with the dentition in their description. Inasmuch as the faunas of Thousand Creek and Snake Creek are not widely separated in time, one unavoidably considers the possibility that the teeth of the twisted-horned forms of the Thousand Creek fauna are not represented among the remains thus far collected at Thousand Creek, while at Snake Creek the teeth of these forms have been found without accompanying horns. Such an explanation seems, however, not to be within the limits of probability.

It would seem to the writer that with the evidence available we are not in a position to determine the affinities of the American twisted-horned antelopes with certainty. So far as can be determined they appear to be near the Antilocapridae, but they are evidently generically distinct from *Sphenophalos*. If, as seems probable, the only type of dentition known from the Thousand Creek Beds really represents this group along with *Sphenophalos*, these forms are probably derived with the Antilocapridae from some type like *Merycodus*, and are not closely related to the Old World strepsicerine forms. If teeth like those obtained by Matthew and Cook at Snake Creek belong to this group it may represent an immigration of typical Old World forms or might be derived from a Palaeomeryx-like American form.

With the available information it is probably desirable to refer *Ilingoceros* tentatively to a distinct family, the Ilingoceridae, and to include *Sphenophalos* in the Antilocapridae.

TRAGOCERAS(?) or ILINGOCEROS

In a former publication[31] the writer provisionally referred

[30] Matthew, W. D., and Cook, H. J., Bull. Am. Mus. Nat. Hist., vol. 26, pp. 413 and 414, 1909.

[31] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 330, 1909.

a fragment of a large horn-core from the Thousand Creek Beds to *Neotragocerus* of Matthew and Cook. This specimen consists of only a fragment representing the tip of a horn. In some respects it is quite similar to the tip of a *Tragoceras* horn. It may, however, represent the terminal portion of a large *Ilingoceros* horn on which the spiral has faded out before reaching the superior end. The surface structure is apparently less tragocerine than antilocaprine, though it is not easy to judge of this character in the terminal portion of the horn.

Transmitted February 15, 1911.

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A SERIES OF EAGLE TARSI FROM THE PLEISTOCENE OF RANCHO LA BREA

BY

LOYE HOLMES MILLER

BERKELEY

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CONTENTS

Introduction

Attention has already been called to the fact that the conditions under which the Rancho La Brea birds were entrapped and preserved were especially conducive to the preservation of the tarsometatarsus.[1] This bone is so characteristic a part of the avian skeleton and reflects so readily the characters of the species that in discussing a large amount of material, such as that assembled in the University of California collections, there should be no hesitation in asserting the identity of the specimen to be considered when based on the characters of the tarsometatarsus. The above principle is especially true of the Acciptres, a group in which the tarsometatarsus is even more distinctive than is the raptorial beak.

[1] Miller, L. H., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, p. 1, 1910.

The present discussion includes all the buteonid material pertaining to species that were evidently larger than *Archibuteo ferrugineus.* This material forms a series of sixty almost perfect tarsometatarsi. The slight imperfections consist in the main of fractures only, there being almost no corrosion. The surface of the bone is as smooth as in newly macerated specimens and assumes, in cleaning, a beautiful polish with every rugosity and every intermuscular line perfectly distinct. Four specimens of Recent American eagles are at hand for comparison. *Aquila* is represented by one specimen, a large bird fully adult. *Haliaëtus* is represented by an individual taken at Long Island, N. Y., which belongs to the variety *leucocephalus,* and also by a specimen of the Alaskan race *alascanus,* a large female in the collection of the California Museum of Vertebrate Zoology. The peculiar long-shanked group of South American eagles is represented by a single specimen of *Geranoaëtus melanoleucus,* an adult individual of unknown sex. Various smaller American buteonids are at hand, also four Old World forms from the genera *Otogyps, Neophron, Circaëtus* and *Gypaëtus.*

Besides the actual specimens named, two casts were available for comparison. These casts were made through the courtesy of Dr. A. Smith-Woodward and represent the tarsometatarsi of *Thrasaëtus harpya* and *Morphnus guianensis.* They are casts of specimens in the British Museum of Natural History. It is a pleasure here to acknowledge the service rendered by Dr. Smith-Woodward.

The fossil specimens fall easily into five distinct series, each of which shows a remarkable degree of homogeneity, and each of which unquestionably represents a form specifically distinct. Most of the series are large enough to include all individual variations that could reasonably be expected to occur in the limits of a species as the result of varying age, sex, or individuality. The two largest of these series represent the existing Sonoran species *Aquila chrysaëtos* and *Haliaëtus leucocephalus.* Since, however, a detailed discussion of the tarsometatarsus of these forms was not discovered in the literature upon attacking the present problem, it is hoped that a comparison of the two forms here will not prove superfluous.

Description of Species

AQUILA CHRYSAËTOS (Linnaeus)

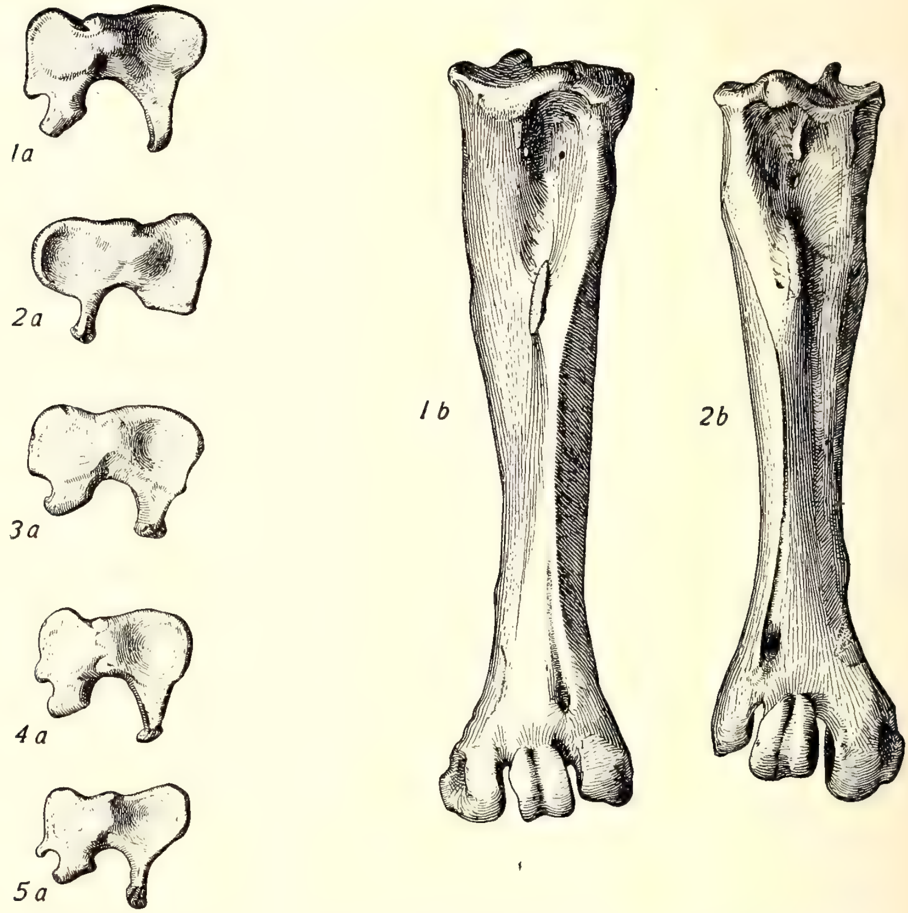
Twenty-nine almost perfect tarsi represent this existing species. Except in the matter of size there is almost no perceptible variation in the specimens of the entire series. A greater or less distinctness in the rugosities about the head of the bone to which the articular ligaments attach is here ascribed to age of the individual. The positions of these rugosities are very constant and form one of the bases of distinction between the genera *Aquila* and *Haliaëtus.* Differences in size of the two extremes of the series are quite noticeable; there is, however, a complete intergradation in this respect. This variation is, in all probability, due to sex and individuality combined, large males intergrading with the smaller females in regard to size of tarsometatarsus.

The most noticeable differences between this series and the *Haliaëtus* series lie in the characters of the head region of the bone. When viewed from the front, the depression into which the two proximal foramina open is deep and sharply delineated on all sides except the distal side. The inner margin of this depression just even with or but slightly above the internal, proximal foramen is marked by an elongate, ridge-like papilla which is the outer attachment of the ligamentous supratendinal bridge. In the genus *Haliaëtus*, the proximal depression is very shallow and ill defined and the outer attachment of the ligamentous bridge lies almost directly above the interior proximal foramen. The tubercle of the tibialis anticus is much the same except that it is placed further down the shaft in *Aquila.* On viewing the bones from their proximal articular faces, the two species are at once distinguishable by the much greater development in *Aquila* of the outer ridge of the hypotarsus. In *Haliaëtus* this portion appears as a rounded hillock, whereas in *Aquila* it is developed into a strong unciform process.

Minor differences lie in the positions of the proximal foramina. These are placed close together in *Haliaëtus* and the outer is almost invariably raised appreciably above the inner. The reverse is true of the foramina in *Aquila.* In the latter genus the inner attachment of the ligamentous bridge is usually less distinct and less elongate than in the former. The length of the bone in *Aquila* averages greater and the robustness less. The inner trochlea is larger in every respect, the outer trochlea is more compressed laterally.

None of the bones in the large series of *Aquila* surpasses in size the single specimen of the Recent phase which is at hand. The evidence furnished by the group of fossil tarsometatarsi is

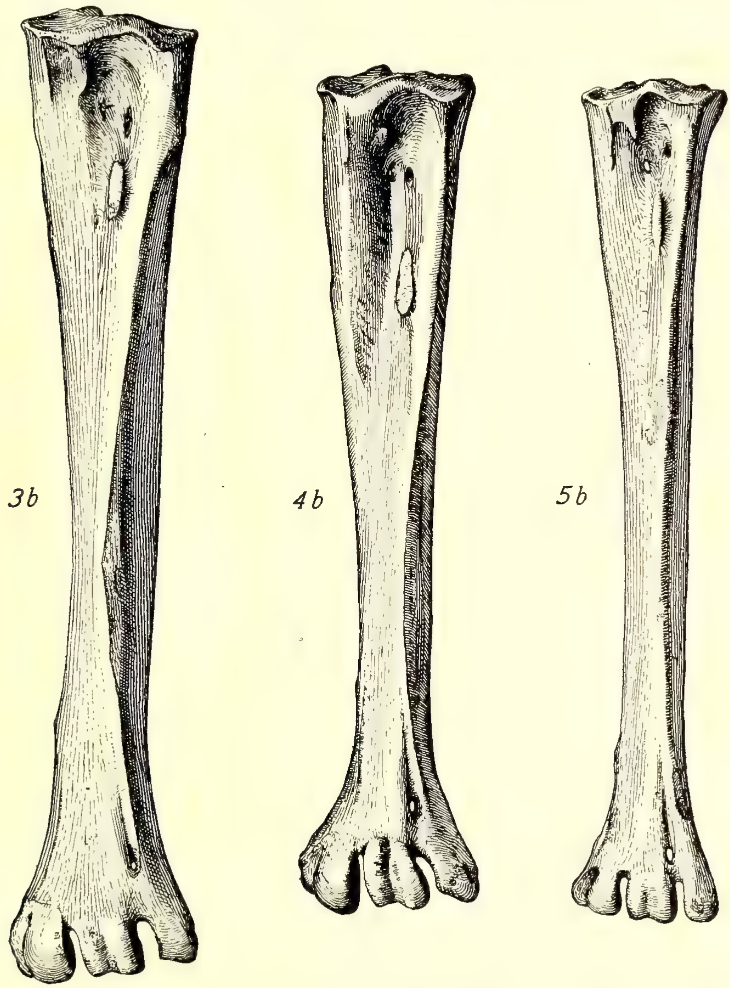
such as to indicate that *Aquila chrysaëtos* was abundant and probably the dominant eagle of the region during the Pleistocene, and that it has remained till the present time practically unchanged.



Figs. 1*a* to 5*b*. The anterior faces and the proximal articular surfaces of the tarsometatarsi. All figures natural size. From the Pleistocene of Rancho La Brea.

Figs. 1*a*-1*b*. *Aquila chrysaëtos* (Linnaeus). No. 12788.
Figs. 2*a*-2*b*. *Haliaëtus leucocephalus* (Linnaeus). No. 12789.
Fig. 3*a*. *Morphnus woodwardi*, n. sp. No. 12787.
Fig. 4*a*. *Geranoaëtus grinnelli*, n. sp. No. 12175.
Fig. 5*a*. *Geranoaëtus fragilis*, n. sp. No. 12757.

Mention has been made of the occurrence in the asphalt of large numbers of this species.[2] A survey of the entire collection of birds in the collections of the Department of Palaeontology at the University shows it to outnumber by 100 per cent any other



Figs. 3*b* to 5*b*. Anterior faces of tarsometatarsi. All figures natural size. From the Pleistocene of Rancho La Brea.

Fig. 3*b*. *Morphnus woodwardi*, n. sp. No. 12787.

Fig. 4*b*. *Geranoaëtus grinnelli*, n. sp. No. 12175.

Fig. 5*b*. *Geranoaëtus fragilis*, n. sp. No. 12757.

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[2] Miller, L. H., Univ. Calif. Publ., Bull. Dept. Geol., vol. 5, pp. 305-317, 1909.

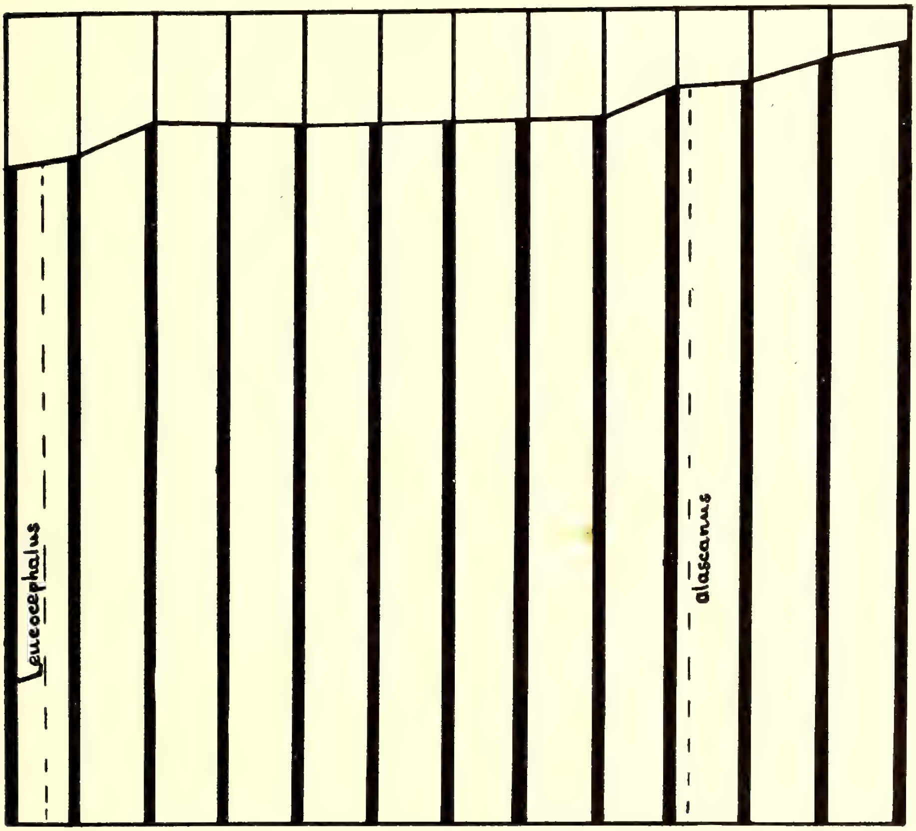
species represented. Despite the fact that eagles are known to resort to carrion diet at times, the great preponderance of this bird's remains over those of other avian species is surprising. Was the golden eagle numerically so much more abundant than any of the vultures as to have outnumbered all species of that group despite its less habitual resort to carrion? Was its feeding upon carrion a matter of more common occurence then than now? A greater numerical abundance owing to the absence of man, one of its chief enemies, may have sharpened competition to such a degree as to compel it oftener to resort to such a habit. Again, was the submersion of the carcass of the entrapped mammal more rapid than we have hitherto considered so that it remained attractive to the predatory form almost as long as it was exposed to view?

HALIAËTUS LEUCOCEPHALUS (Linnaeus)

This species is represented by a series of thirteen tarsometatarsi from the asphalt and by Recent specimens of the two subspecies at present recognized by American ornithologists. The largest of the fossil series exceeds both in length and in robustness the large female of *H. l. alascanus* at hand, while the smallest specimen is quite noticeably less than the Recent *H. l. leucocephalus* taken at Long Island. The intergradation in size and the homogeneity of characters is perfect throughout the series.

There seems to have existed in Southern California during the Pleistocene a generalized stock of this species which was subject to a wide range of variation on either side of a norm lying intermediate between the varieties at present recognized as *H. leucocephalus* and *H. alascanus.* In the series of fossil tarsometatarsi at hand, there appears no suggestion of a splitting of the species by a grouping about two norms. *Alascanus* and *leucocephalus* are at present separated geographically by a somewhat elastic barrier of temperature corresponding almost exactly with the northern limit of the Sonoran region of Arctogaea as determined by the distribution of Recent Mammalia. There appears to have occurred in the species since Pleistocene time a selection based upon adaptation to climatic conditions causing the retraction of a larger phase to the northward and a smaller to

the southward, or as it may be otherwise stated, a highly variable Pleistocene species has responded to the environment of a



Plot of the lengths of the twelve tarsometatarsi of the fossil phase of *Haliaëtus leucocephalus*. Recent specimens of the subspecies of *alascanus* and *leucocephalus* are interpolated in dotted lines. The vertical distances from the base line represent the actual lengths of specimens as measured in millimeters.

colder climate by producing a preponderance of large individuals and to that of a warmer climate by the production of smaller ones.

MORPHNUS WOODWARDI, n. sp.[3]

Type specimen no. 12787, Univ. Calif. Col. Vert. Palae. Tarsometatarsus. Resembling *Aquila* in general but thirty per cent longer; shaft narrower, ligamentous bridge shorter; anterior proximal depression shallower and less defined; papilla of tibialis anticus placed much higher on the shaft; ridges of the hypotarsus less produced; foot narrower and trochleae smaller.

This species is based on a single perfect specimen excavated at Rancho La Brea by the author. It was added to the University collection on account of its uniqueness. The bird represented was evidently an adult, since the intermuscular lines, the tubercles and the foramina show complete ossification.

The establishment of this species was delayed for some time by the absence of any first-hand impression of the existing *Thrasaëtus harpya.* It seemed scarcely probable from descriptions of *Thrasaëtus* in the flesh that there could be any great degree of similarity between the two forms, yet the linear dimension of the tarsometatarsus of *Thrasaëtus,* the only measurement available, corresponded very closely with the same dimension of the fossil form. The splendid cast of *Thrasaëtus* sent by Dr. Smith-Woodward showed at a glance the enormous difference that separates the two species. The Rancho La Brea specimen exceeds by ten millimeters the length of the cast, and yet it has but little more than half the transverse diameter of shaft. In its general contours *Thrasaëtus* appears more as a gigantic *Haliaëtus.* The fossil form on the other hand suggests an extremely elongate *Aquila.*

The differences between *Morphnus* and *Geranoaëtus* as displayed by the tarsometatarsus are slight, and are limited so far as is noticeable to the head region of the bone. In *Geranoaëtus* the anterior face in this region resembles *Haliaëtus* in the great length of the supratendinal bridge. The crest marking its external end falls almost in the center of the bone as in *Haliaëtus.* This face of the bone is also less abruptly excavated—a character distinguishing *Haliaëtus.* A further distinguishing

[3] This form is given its specific name in honor of Dr. A. Smith-Woodward of the British Museum of Natural History.

character appears when the proximal articular surface is viewed. The inner hypotarsal ridge shows much the greater development in *Geranoaëtus.*

Upon these grounds the three fossil species of long shanked eagles are referred to the two existing genera, *Morphnus* and *Geranoaëtus.*

Morphnus woodwardi appears to have been a rather weak-footed form, as indicated by the slender shaft, small trochleae, weak hypotarsal ridges, small supratendinal loop, and high position of the papilla of the tibialis anticus. The same indications of weakness are to be seen in the long shanked *Geranoaëtus melanoleucus,* a species reported to feed upon offal. The mechanical advantage sacrificed by thus attaching the tibialis anticus so high up the shaft must be quite appreciable. The shortening of the power arm in the lever of flexion of the foot would, other factors being equal, diminish the lifting power of this segment of the limb.

In several species of falconids at hand, the relation of the power arm as indicated by the position of the papilla of the tibialis anticus, to the total length of the shaft, has been calculated and is recorded in the table below.

	Resistance arm	Power arm	Ratio
Thrasaëtus harpya (cast)	117.1 mm.	32. mm.	27.3%
Aquila chrysaëtos	100.2	30.3	30.2
Haliaëtus leucocephalus alascanus	97.7	23.	23.5
Archibutio ferrugineus	89.	21.	23.5
Buteo borealis	85.5	17.1	20.
Falco peregrinus	57.5	11.	19.1
Geranoaëtus melanoleucus	114.	21.	18.4
Morphnus guianensis (cast)	103.9	17.1	17.1
Morphnus woodwardi	129.1	21.5	16.6
Otogyps calvus	111.5	18.	16.1

In the collection of the Los Angeles High School, there is a specimen of the tarsometatarsus of this species. The specimen was placed in the author's hands by the instructor of zoology at that institution, Mr. J. Z. Gilbert, for examination. This specimen measures 137.2 mm. in total length, thus exceeding by eight millimeters the type specimen. In the details of its contours it corresponds perfectly with the type specimen.

Dimensions of the Type Specimen

Tarsometatarsus—	
Length over all	129.1 mm.
Length to middle of papilla of tibialis anticus	21.5
Transverse diameter of head	22.5
Transverse diameter of foot	24.
Least transverse diameter of shaft	10.8
Sagittal diameter of head	17.2

GERANOAËTUS GRINNELLI, n. sp.[4]

Type specimen no. 12175, Univ. Calif. Col. Vert. Palae. Tarsometatarsus in perfect preservation. Resembles *Geranoaëtus melanoleucus* in general, but is slightly more robust and shows superior strength by greater production of the hypotarsal ridge and lower position of the papilla of the tibialis anticus.

Details of comparison are as follows: Anterior view. The proximal depression is not so deep; the proximal foramina are very close together and almost on the same level; and the outer attachment of the ligamentous bridge is in the form of a rounded papilla instead of an elongate ridge. The head of the bone at the extreme summit is just equal in width to that of *G. melanoleucus*, but narrows less rapidly as it merges into the shaft, The papilla of the tibialis anticus is of about the same size, but is placed farther down the shaft, thus giving a ratio of power to weight arm of 23.8% as against 18.4% in *G. melanoleucus.* The distal foramen is larger and the furrow leading to it is deeper and more perfectly defined. The trochleae are practically identical in the two species.

Posterior aspect—The most striking differences noted from this aspect are the closer approximation of the hypotarsal ridges and the prolongation of the inner ridge to a greater distance down the shaft. Aside from the stouter shaft, no other difference is appreciable from the rear.

Proximal articular surface—From this viewpoint the fossil form presents three points of divergence from the Recent species. The anterior and the external borders are both indented instead of being nearly straight. The external articular facet thus assumes a more rounded outline. The hypotarsal ridges are produced to a greater degree and, although the space included between them is narrower, the inner ridge seems less deflected toward the median line. The cross-section of the hypotarsal groove thus presents a quite different outline.

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[4] This species is named in honor of Mr. Joseph Grinnell, Curator of the California Museum of Vertebrate Zoology, and one of the foremost students of the distribution of west American birds.

DIMENSIONS OF THE TYPE SPECIMEN

Tarsometatarsus—

Length over all	109. mm.
Length to papilla of tibialis anticus	26.
Transverse diameter of head	20.
Transverse diameter through trochleae	22.5
Least transverse diameter of shaft	10.
Greatest sagittal diameter of head	17.3

GERANOAËTUS FRAGILIS, n. sp.

Type specimen no. 12757, Univ. Calif. Col. Vert. Palae., tarsometatarsus. When compared with *G. melanoleucus* this form exhibits the following characters: Length equal to *G. melanoleucus,* but width much less; position of papilla of tibialis anticus much higher; proximal depression and proximal foramina much the same. Antero-exterior ridge of shaft sharper; inner hypotarsal ridge placed much nearer center of the shaft, the hypotarsal ridges very close together and the intervening furrow more than a semicircle in cross-section.

In size the closest resemblance of this species is to *Geranoaëtus grinnelli.* It is, however, distinguishable by its greater slenderness, the higher position of the papilla of the tibialis anticus, the greater distance between the proximal foramina, the shorter supratendinal bridge, and the elongation of the papilla at the inner end of this bridge into a vertical crest which merges upward into the margin of the proximal articular surface. On the posterior side the inner hypotarsal ridge is not prolonged downward along the shaft, but is stopped abruptly by the posterior opening of the internal proximal foramen. This foramen in each of the four specimens of the series opens posteriorly exactly at the lower limit of the hypotarsal ridge, whereas in the nine specimens of *Geranoaëtus grinnelli,* the base of the inner ridge extends down the shaft beyond the foramen and on its inner side.

This species is represented by a series of four tarsometatarsi which display a remarkable degree of uniformity. The slight variation in heaviness is ascribed to difference in sex. The extreme of specialization among the larger buteonids toward an elongate and slender tarsometatarsus seems here to have been reached. The transverse diameter of the head, foot and shaft are almost exactly equal to the corresponding dimensions in *Archibuteo ferrugineus,* while the length exceeds that of *Aquila* and equals that of *Geranoaëtus melanoleucus.* The relation of power arm to weight arm in the flexure of the tarsal joint is 16.6%, a

ratio just equal to that in *Morphnus woodwardi* and far inferior to that in *Geranoaëtus grinnelli.*

DIMENSION OF THE TYPE SPECIMEN

Tarsometatarsus—	
Length over all	112.6 mm.
Length to center of papilla of tibialis anticus	18.6
Transverse diameter of head	18.
Transverse diameter of foot	19.4
Least transverse diameter of shaft	8.1
Sagittal diameter of head	14.8

COMPARATIVE TABLE OF MEASUREMENTS OF TARSOMETATARSI IN THE ENTIRE SERIES

	Maximum	Minimum	Average
Aquila chrysaëtos. 29 specimens—			
Total length	103.6 mm.	92.1 mm.	102.2 mm.
Transverse diameter of head	23.5	19.	21.5
Transverse diameter through trochleae	25.5	21.	23.3
Haliaëtus leucocephalus. 13 specimens—			
Total length	103.	87.	94.7
Transverse diameter through head	24.6	20.7	22.5
Transverse diameter through trochleae	28.	21.5	24.7
Geranoaëtus grinnelli. 9 specimens—			
Total length	112.8	104.8	108.4
Transverse diameter through head	....	....	....
Transverse diameter through trochleae	20.8	17.4	19.6
Geranoaëtus fragilis. 4 specimens—			
Total length	112.	103.	107.5
Transverse diameter through head	18.	17.	17.5
Transverse diameter through trochleae	19.5	17.8	18.7

Morphnus woodwardi. 1 specimen—	
Total length	129.1 mm.
Transverse diameter through head	22.5
Transverse diameter through trochleae	24.

Transmitted July 11, 1911.

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NOTES ON THE RELATIONSHIPS OF THE MARINE SAURIAN FAUNA DESCRIBED FROM THE TRIASSIC OF SPITZBERGEN BY WIMAN

BY

JOHN C. MERRIAM

NOTES ON THE DENTITION OF OMPHALOSAURUS

BY

JOHN C. MERRIAM AND HAROLD C. BRYANT

BERKELEY

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NOTES ON THE RELATIONSHIPS OF THE MARINE SAURIAN FAUNA DESCRIBED FROM THE TRIASSIC OF SPITZBERGEN BY WIMAN

BY

JOHN C. MERRIAM

CONTENTS

INTRODUCTION

Since Nordenskiold's discovery of a number of fragmentary ichthyosaurian specimens in the Triassic of Spitzbergen in 1864[1] the hope has often been expressed that we might know more of the saurian fauna of this interesting region. Though additional material has been obtained from time to time,[2] it was not until recently that any considerable number of specimens was brought together for study.

In 1908 and 1909 important collections were obtained at Spitzbergen by Carl Wiman and Bertil Högbohm, making pos-

[1] Hulke, I. W., Bih. till K. Vet. Akad. Handl. Bd. 1, No. 9. 1873.

[2] Yakowlew, N., Verh. d. Russ. Kais. Min. Ges. St. Petersb. Ser. 2, Bd. 40, p. 179. 1902.

sible a more satisfactory determination of the nature of the saurian forms represented in this fauna than had previously been possible. The results of a study of the collection by Wiman[3] form a most interesting and important contribution to our knowledge of this group, and materially assist in comparison of the Spitzbergen Triassic with that of the rest of the world.

OCCURRENCE

The ichthyosaurian remains from Spitzbergen are described by Wiman as occurring in two horizons of the middle Trias. The upper horizon is in the Daonella shales, and contains abundant specimens of the ammonite genus *Ptychites.* The saurian collection from the upper beds comprises *Mixosaurus*(?) *nordenskioldii* (Hulke), and *Pessosaurus polaris* (Hulke).

The lower saurian horizon is about three hundred and fifty feet below the upper beds. Below it is an ammonite fauna including *Ceratites polaris.* At this horizon two saurian forms were found, which are described as *Pessopteryx nisseri,* n. gen. and sp., and *P. minor.* A short distance below the lower horizon a number of large ichthyosaur teeth were found.

Excepting the specimens representing *M.*(?) *nordenskioldii,* all of the material from Spitzbergen unfortunately consists of scattered or isolated bones. The *M.*(?) *nordenskioldii* specimens are much better preserved than the others, and in some cases show considerable connected parts of skeletons.

MIXOSAURUS(?) NORDENSKIOLDII (Hulke)

Both *Mixosaurus*(?) *nordenskioldii* and *Pessosaurus polaris* were first described by Hulke in 1873 under the name of *Ichthyosaurus.* Since that time it has been clear to several writers that they could not remain in that genus, and various suggestions as to their possible relationships have been made by Dames,[4] Yakowlew,[5] and Merriam.[6]

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[3] Wiman, Carl, Ichthyosaurier aus der Trias Spitzbergens, Bull. Geol. Inst. Upsala, vol. 10, pp. 124-148. 1910.

[4] Dames, W., Sitzb. d. Acad. d. Wiss. Berlin, 1895, p. 1045.

[5] Yakowlew, N., Verh. d. Kais. Russ. Min. Ges. Bd. 40, p. 179. 1902.

[6] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol. vol. 3, pp. 87, 88. 1902.

Wiman's studies of *M.(?) nordenskioldii* make possible for the first time a fairly satisfactory suggestion as to the affinities of this form. From a study of the excellently preserved material of this species Wiman has been able to show the close similarity of this form to *Mixosaurus cornalianus* from the Besano beds of northern Italy, and also to the imperfectly known *Cymbospondylus(?) natans* from the Middle Triassic of the West Humboldt Range in Nevada.

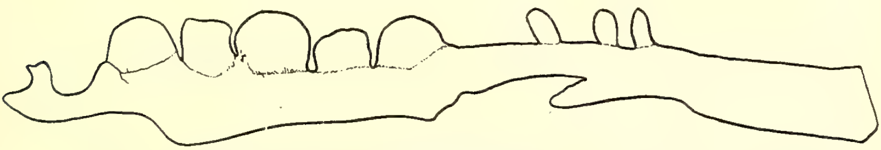

Fig. 1. *Mixosaurus(?) nordenskioldii* (Hulke). A portion of the lower jaw with dentition. Natural size. (After Wiman).

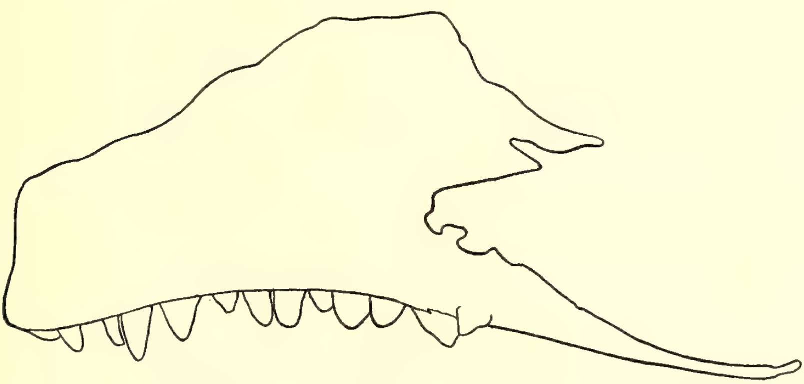

Fig. 2. *Mixosaurus(?) nordenskioldii* (Hulke). Upper jaw fragment with dentition. Natural size. (After Wiman).

The *skull* of *M.(?) nordenskioldii* is known only by a few fragments. Fortunately in many instances these pieces bear teeth, so that some important characteristics of the dentition appear. As was shown by Dames, the *dentition* is thoroughly differentiated. The posterior teeth are low, laterally-compressed domes, the anterior teeth are small, approximately conical, and round in cross-section. The roots are coarsely folded as in the

specimens of *M.* (?) *atavus* described by Fraas,[7] from the middle Trias of Germany, and are set in more or less distinctly separated alveoles. The dentition in several specimens, as appears in figure one adapted from Wiman, is very close to that of *Phalarodon,* a Nevada Middle Triassic form recently described[8] by the writer. The teeth of other specimens (fig. 2) are less like *Phalarodon* and more like *Mixosaurus* of the Italian Triassic. It seems not impossible that two types are represented in Wiman's material.

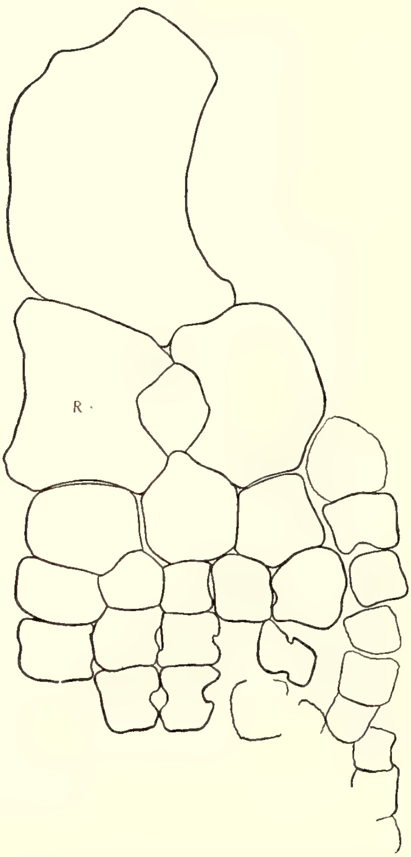

Fig. 3. *Mixosaurus* (?) *nordenskioldii* (Hulke). Anterior limb, × ⅔. R, radius. (After Wiman).

One of the most interesting discoveries made by Wiman is the finding of excellent material representing the *limbs* and arches of *M.* (?) *nordenskioldii.* Both anterior and posterior limbs were obtained in such excellent state of preservation that nearly all the essential characters can be determined. In both limbs the epipodial elements are distinctly elongated and separated by a median cleft as in most Triassic ichthyosaurs, and the phalangeal elements generally show the median constriction, which has been considered as representing a rudimentary shaft region.

The *anterior limb* (fig. 3) is in general much like that of *Mixosaurus cornalianus* of the Italian Triassic. It differs from

[7] Fraas, E., Ichthyosaurier der Süddeutschen Trias-und-Jura-Ablagerungen, 1891, p. 38; Taf. 1, figs. 17 and 18, and Taf. 3, figs. 2 and 3.

[8] Univ. Calif. Publ. Bull. Dept. Geol. vol. 5, p. 382. 1910.

the Italian specimens thus far described in possessing a sixth digit. The first three segments of the anterior limbs are practically identical with those of *Cymbospondylus* (?) *natans*, a Mixosaurus-like species from the Middle Triassic of Nevada. The *posterior limb* (fig. 4) is almost identical in form with that of *Mixosaurus cornalianus*, even to the duplication of a peculiar arrangement of the proximal carpals found in the Italian species.

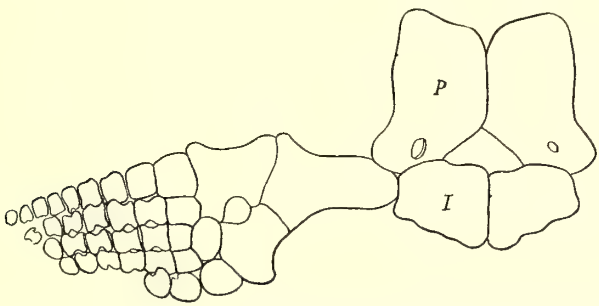

Fig. 4. *Mixosaurus* (?) *nordenskioldii* (Hulke). Pelvic arch and posterior limb, × ½. P, pubis; I, ischium. (After Wiman.)

The *pelvic arch* (fig. 4) is almost identical with that in most specimens of the American *Cymbospondylus*, and differs from that of *Mixosaurus* in the absence of an obturator foramen in the pubis.

The *pectoral arch* is like that of *Mixosaurus* excepting in the form of the interclavicle, which has a remarkably wide triangular form with a distinct reëntrant angle on the anterior side.

The complete *vertebral column* is not known, but fortunately considerable numbers of vertebrae, including the posterior dorsal region and a large part of the tail, were found in a continuous series (fig. 5). As in *Mixosaurus cornalianus*, the tail makes a gentle upward curve near the middle and droops slightly at the posterior end. In the Spitzbergen form as represented in the specimen figured by Wiman the upward curve is much nearer the dorsal region than in *M. cornalianus;* in contrast to *Cymbospondylus*, in which the curve is farther back than in the Italian species.

The posterior dorsal and the caudal vertebrae are characterized by very high, slender neural arches. The arches stand nearly erect over the posterior dorsal and anterior caudal regions, but are suddenly turned sharply forward near the middle of the

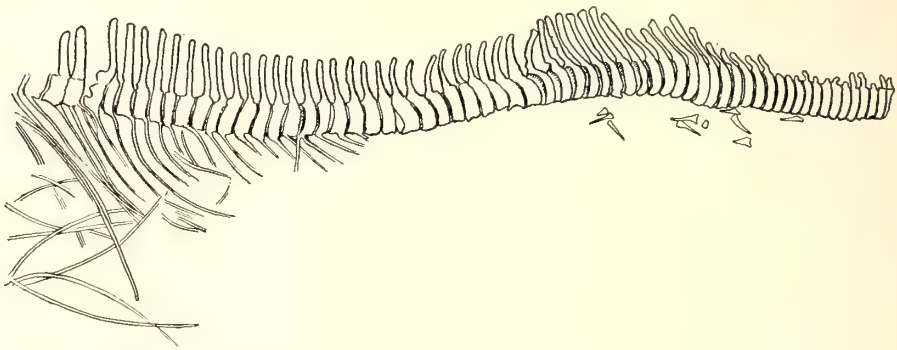

Fig. 5. *Mixosaurus*(?) *nordenskioldii* (Hulke). A portion of the dorsal and caudal series, × ⅕. (After Wiman).

bend in the tail. The centra of the caudal region are considerably increased in both relative and absolute height behind the middle of the bend, and are very noticeably flattened laterally.

In a reconstruction of *Mixosaurus nordenskioldii* published by Wiman (fig. 6) the expansion of the caudal fin is represented

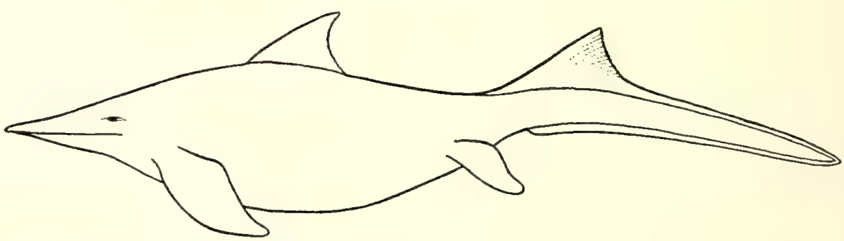

Fig. 6. Restoration of *Mixosaurus*(?) *nordenskioldii* (Hulke). (After Wiman).

as widest at a point only a short distance posterior to the pelvic limb. Wiman's reconstruction is apparently based on the proportions of a specimen showing the posterior dorsal and caudal region as reproduced in figure five. In this specimen as figured there is an extraordinarily sudden lengthening of the neural

spines immediately behind a break in the specimen, which suggests, as a bare possibility, the loss of a portion of the caudal series at this point. It is also worthy of note that the original position of the pelvis is very difficult to determine, and it may easily have been situated considerably farther forward than the point in the column below which the ilium now rests. A modification in one or both of these particulars might change the relative position of the upper lobe of the caudal fin. It would seem to the writer that a propeller constructed as represented in this form would be far from the most efficient type. It would also represent a distinct deviation from what appears to be the natural line of evolution of the typical ichthyosaur out of a Palaeohatteria-like shore form. In an earlier publication[9] the writer has suggested that the probable course of evolution of the ichthyosaurian caudal fin has been through a series of forms in which the tail fin was first distinctly adapted for service as a propeller by increase in height some distance anterior to the tip through elongation of the neural arches. This was possibly accompanied by a slight droop of the extreme posterior region. Through the stages of *Cymbospondylus* (?) *natans* and *Mixosaurus cornalianus* a superior lobe developed over the elongated spines. Once developed, this lobe remained and increased in importance. The support of the neural spines came to be unnecessary and their arches were much reduced in the later stages of evolution of the group.

The *rib articulation* is not clearly shown for the whole vertebral series, and is unfortunately not known in the cervical and anterior dorsal regions. Some of the vertebrae bear widely separated diapophyses and parapophyses as in *Toretocnemus* from the West American Triassic. These centra are from the middle or posterior dorsal region.

PESSOSAURUS POLARIS (Hulke)

A number of specimens representing a large saurian from the upper bed are included by Wiman in Hulke's species *Ichthyosaurus polaris,* which is, however, separated as a distinct

[9] Merriam, J. C., Triassic Ichthyosauria, Mem. Univ. Calif., vol. 1, p. 40. 1908.

genus *Pessosaurus*. If the several specimens referred to this genus actually belong together, the only distinguishing character of the group would seem to be in the humerus. The element considered as the femur is like that of *Shastasaurus*. The short humerus is nearly circular in form, and differs from that of *Shastasaurus* in the absence of any trace of a median constriction. In the most specialized forms of *Shastasaurus* the humerus is relatively shorter than in *P. polaris*, but evidence of an original median constriction appears in the anterior and posterior notches. The carpal and phalangeal elements of *Pessosaurus* are apparently round, and evidently lay in a cartilage plate as in *Shastasaurus* and in *Baptanodon*.

PESSOPTERYX

Of the specimens referred to *Pessopteryx* the only remains of the skull consist of jaw fragments, of which the exact position in the skull is not known. The teeth carried by these fragments are numerous, and the hemispherical crowns seem to be set in many rows. They were first thought by Wiman to be pavement teeth of fishes, but against this idea he has rightfully urged that they are numerous, and are the only teeth occurring with the saurian remains in the lower horizon. The presumption is in favor of the view that they represent the same form as some of the saurian bones. As is suggested by Wiman, the dentition represented in these specimens differs from that of ichthyosaurs in the quite uniformly smooth, hemispherical tooth-crowns, and in their arrangement in numerous rows. In one specimen figured, the roots are shown to have infolded walls, as in the Ichthyosauria. It is, however, worth noting that the figured specimen (Wiman, pl. 9, fig. 30) showing the folded root-structure is much larger than any of the others. The specimen shown in Wiman's figure 26, plate 9, which most nearly approaches in size the specimen with a slightly folded root-structure, does not certainly show the arrangement of teeth in several rows. The combination of characters seen in this dentition is quite unlike that of any known member of the Ichthyosauria. Very low, domed tooth-crowns are known in the most posterior teeth of the

genus *Phalarodon*,[10] but in this and in other somewhat similar primitive ichthyosaurs the teeth are in a single row, and the low-crowned posterior teeth rapidly change to a sharply conical form in the middle and anterior region of the jaw. In all of the characters mentioned, excepting in the folded roots, the peculiar teeth on most of the specimens figured by Wiman resemble the dentition of the genus *Omphalosaurus* from the Middle Triassic of Nevada.[11]

Omphalosaurus was described from a single specimen representing a skull with a portion of the dentition. A few vertebrae were connected with the skull, and several limb bones were doubtfully associated with it. The structure of the skull was not clearly understood, but it did not seem to correspond to that of any known reptilian family. The inferior dentition consisted of several rows of hemispherical, to low-conical teeth on each dentary. The inferior dentition collectively formed a strongly convex crushing surface, which presumably indicated that the facial region was short. Other specimens which have been obtained at the same horizon as the original one show the dentition better than in the type. In each case the tooth-crowns preserve a nearly unvarying form, and the surface of the tooth-pavement is convex.

Other skeletal remains which have been thought by Wiman to represent the same genus as the jaws bearing hemispherical teeth comprise a number of vertebrae and many elements representing the limbs and arches. The vertebrae are not distinctly different from those of certain Triassic ichthyosaurs. So far as can be determined this may also be true of the vertebrae associated with the type specimen of *Omphalosaurus*. The limb bones referred to *Pessopteryx* are all such as might belong to an ichthyosaur of the type of *Shastasaurus*. Short limb elements of a similar nature were associated with the type specimen of *Omphalosaurus*, but were not described, as there seemed a possibility that the association was purely accidental. While one

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[10] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol. vol. 5, p. 383. 1910.

[11] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol. vol. 5, p. 76. 1906.

would not be justified in holding that all of the limb elements referred by Wiman to *Pessopteryx* actually represent the same genus as the jaws with button-like teeth, there seems a reasonable possibility that some of them belong to that group.

It seems to the writer probable that some, if not all, of the Spitzbergen forms with button-like teeth arranged in several rows are referable to a genus closely allied to *Omphalosaurus*. It would not be surprising if there were associated with these a number of specimens of ichthyosaurs of the *Phalarodon* type. This is at any rate precisely the association found in the Middle Triassic of Nevada.

FAUNAL RELATIONSHIPS

The saurian forms represented in the Triassic of Spitzbergen show a noticeable similarity to those of the Triassic of western North America and of central and southern Europe. *Mixosaurus* (?) *nordenskioldii* of Spitzbergen is apparently close to *Mixosaurus cornalianus* of Italy, and seems also nearly identical, so far as known, with *M.* (?) *natans* of the Middle Triassic of Nevada. Some of the Spitzbergen forms referred by Wiman to *Mixosaurus* show a general similarity of the dentition to that of *M.* (?) *atavus* of central Europe, as also to that of *Phalarodon* of the Middle Triassic of Nevada. The resemblance of some of the Spitzbergen specimens included in *Pessopteryx* to *Omphalosaurus* of the Nevada Middle Triassic is such as to suggest close relationship, if not generic identity of the two forms.

The stage of evolution of the Spitzbergen fauna is not easily estimated with the material available. As nearly as can be determined *M.* (?) *nordenskioldii* is near the stage of evolution of *M. cornalianus* and *M.* (?) *natans*. It may be slightly less advanced than *Cymbospondylus*, but difference in size of the individuals compared may prevent a satisfactory determination of the relative stages of advance.

The forms of the *Pessosaurus polaris* type in the Spitzbergen fauna suggest the stage of evolution seen in *Shastasaurus* of the Californian Upper Triassic. It should, however, be stated that fragmentary specimens of a somewhat similar nature have been

seen in the Middle Triassic of Nevada. There is as yet insufficient evidence to permit an interpretation of this Nevada material. It is not impossible that specialized short-limbed forms were beginning to appear in the Nevada Middle Triassic, though not yet an important or dominant type as in the Upper Triassic.

On the whole, such evidence as is available suggests that the saurian fauna of the Spitzbergen Triassic is not far removed in time from the *Cymbospondylus* fauna of the Middle Triassic of Nevada, and that it is also near the age of the *Mixosaurus* fauna of the Besano Beds of Italy. It may also be assumed that at the period in which these faunas flourished there was free communication between the sea areas of the Spitzbergen, Nevada, and north Italian regions.

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NOTES ON THE DENTITION OF OMPHALOSAURUS

BY
JOHN C. MERRIAM AND HAROLD C. BRYANT

INTRODUCTION

In the saurian collections which have been obtained in the marine Middle Triassic of Nevada during the last ten years a number of specimens have appeared which represent a form apparently differing from all known reptilian types. A portion of a skull representing this group was described by Merriam[1] in 1906 as the type of the genus *Omphalosaurus*. In the absence of complete material it was not possible to determine definitely the relationships of the genus, and it may be placed tentatively in a distinct order, the Omphalosauria. So far as known the animal is a short-headed form, presumably of the synapsidan type. The structure of the palate and the mandible are not unlike that in the plesiosaurs, while other characteristics point toward the rhynchocephalian type. One of the remarkable features of this specimen is found in the nature of the dentition. The dentary elements are set with several rows of teeth, the crowns of which are nearly circular in cross-section, and dome-like in elevation. There are at least three rows of teeth on the dentary, with the presumption that many more rows may have been present. The surface of the dentigerous area of the mandible was evidently strongly convex. The nature of the dentition suggests

[1] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol 5, p. 76, 1906.

that of certain fishes, while characters of the skull are unquestionably reptilian.

Since the publication of the original description of this form Wiman[2] has described from Spitzbergen a number of specimens which he refers to the ichthyosaurs, but which are interpreted by Merriam[3] as probably representing omphalosaurians. The specimens obtained by Wiman occurred in beds which are considered as representing the Middle Triassic, and the saurian fauna is in general quite similar to that of the Middle Triassic of the West Humboldt Range, in which the type specimen of *Omphalosaurus* was found.

EVIDENCE PRESENTED BY NEW MATERIAL

In the material most recently obtained from the Middle Triassic of Nevada there are two closely associated specimens showing a great number of large, bluntly-conical teeth resembling in general the teeth of *Omphalosaurus*. Thus far a study of these specimens has failed to reveal the exact relationships of all of the bony elements exposed. The characters of the dentition are much better shown than in the type specimen of *Omphalosaurus*.

One specimen (no. 19452) shows the dentition of a part of

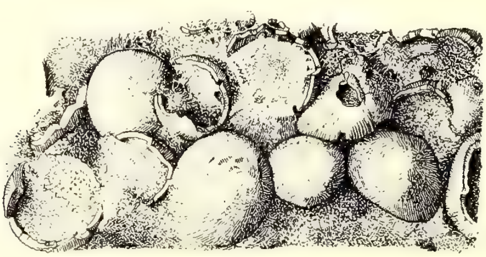

Fig. 1. *Omphalosaurus* (?), sp. A portion of the dentition of the mandible (?). No. 19452, natural size.

what appears to be the dentary. The dentigerous area exposed is a strongly convex surface. The largest and best preserved teeth are situated at the rounded anterior portion. Running pos-

[2] Wiman, C., Bull. Geol. Inst. Upsala, vol. 10, p. 140, 1910.

[3] Merriam, J. C., Univ. Calif. Publ. Dept. Geol., vol. 6, p. 325, 1911.

teriorly on each element the teeth decrease in size. The area having the best preserved teeth shows them in irregular rows. There are at least five rows anteriorly, but only three distinguishable at the posterior extremity of the element. This arrangement, however, is not so apparent on the rest of the dentigerous area, where the teeth are broken off or are crushed together. No part of the elements exposed appears to be edentulous, teeth being found out to the margins.

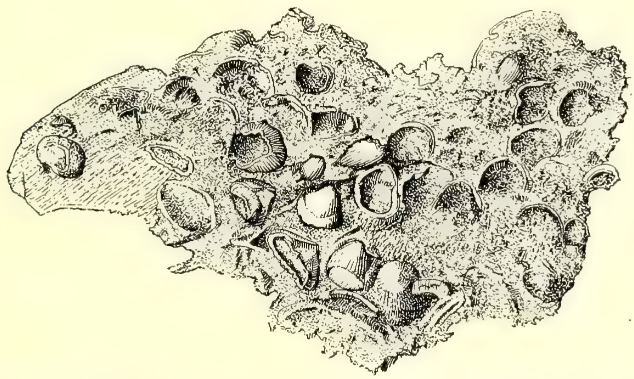

Fig. 2. *Omphalosaurus* (?), sp. Portion of a dentition in which the teeth show a tendency toward a low-conical form. No. 19453, natural size.

The other specimen (no. 19453) apparently shows several of the bones belonging to the skull, and the cross-section of an element bearing nine or ten teeth similar to those on the type specimen.

As nearly as can be determined on the omphalosaur-like material available the teeth rest in distinct pits. The pits vary from two to six millimeters in depth and from three to fifteen millimeters in greatest diameter. In all cases the depth of the pit is less than the greatest transverse diameter, and is nearly the same as the height of the tooth-crown.

The crowns are quite uniformly dome-shaped, with a nearly circular cross-section. The largest tooth measures fifteen millimeters in greatest transverse diameter. The enamel does not appear to be perceptibly roughened. The short, bluntly-conical roots show no radial folding of the dentine as in the ichthyosaurs.

The dentition described does not closely resemble that of any form known to the writers. The evident reptilian character of the skeletal elements precludes any close relationship to the pyconodont fishes or to the cestracionts. Of the reptilian forms the rhynchosaur *Hyperodapedon* has several rows of depressed conical teeth on the maxillary and palatine. They are, however, quite different in size, and apparently in function, while the skull characters of the two forms are far apart. Whatever the relationships of *Omphalosaurus* may prove to be when the skeleton is better known, the dentition is evidently a peculiarly specialized one, which has been adapted to a diet of which shell-covered mollusca formed an important part.

Transmitted July 11, 1911.

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Vol. 6, No. 15, pp. 333-383, pls. 34-43 Issued December 2, 1911

NOTES ON THE LATER CENOZOIC HISTORY OF THE MOHAVE DESERT REGION IN SOUTHEASTERN CALIFORNIA

BY

CHARLES LAURENCE BAKER

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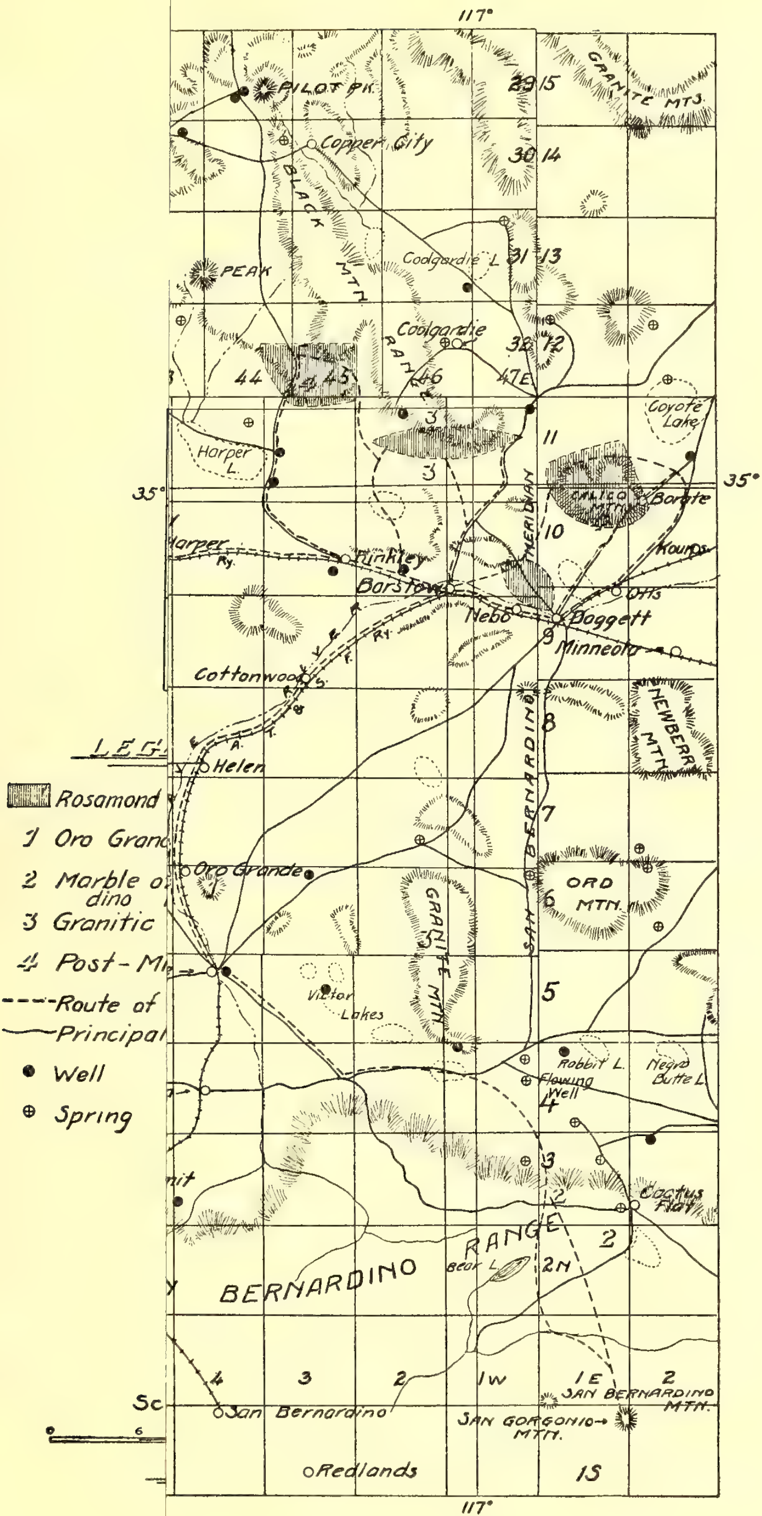
INTRODUCTION

During the spring of 1911 the writer spent a period of two months in the western half of the Mohave Desert and adjoining areas for the purpose of collecting mammalian remains in the fossiliferous formations recently reported to occur in that region.[1] In connection with this work it has been necessary to make a geologic reconnaissance of the formations concerned, and the following paper presents such results as it has been possible to obtain in the progress of the work. The field work was carried on in the interests of the department of palaeontology of the University of California. Mr. Wallace Gordon, of the University of California, assisted in the greater part of the field operations, and Mr. John R. Suman, of the same University, assisted in the examination of the Rosamond locality for the purpose of making a petrographic study of the rocks of that area. The author is also indebted to Mr. J. A. Sampson, Assistant in Petrography in the University of California, for preliminary determinations of rock specimens, and to Professor John C. Merriam for the opportunity of undertaking the work and for numerous suggestions during the progress of the field study and the preparation of the report.

[1] Merriam, J. C., A collection of mammalian remains from Tertiary beds on the Mohave Desert. Univ. Calif. Publ., Bull. Dept. Geol., vol. 6, pp. 163–169, pl. 29, 1911.


117°
PILOT PK.
Copper City
BLACK MTN
GRANITE MTS.
Coolgardie L.
Coolgardie
PEAK
RAND MTS
Coyote Lake
Harper L.
35°
CALICO MTN
Borate
MERIDIAN
Kouns
Harper
Ry.
Hinkley
Barstow
Nebo
Otis
Daggett
Minneola
Cottonwood
NEWBERRY MTN
Helen
SAN BERNARDINO
Oro Grande
ORD MTN.
GRANITE MTN
Victor
Lakes
Rabbit L.
Negro Butte L.
Flowing Well
Cactus Flat
BERNARDINO RANGE
Bear L.
San Bernardino
SAN GORGONIO MTN.
SAN BERNARDINO MTN.
Redlands
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Rosamond
1 Oro Grand
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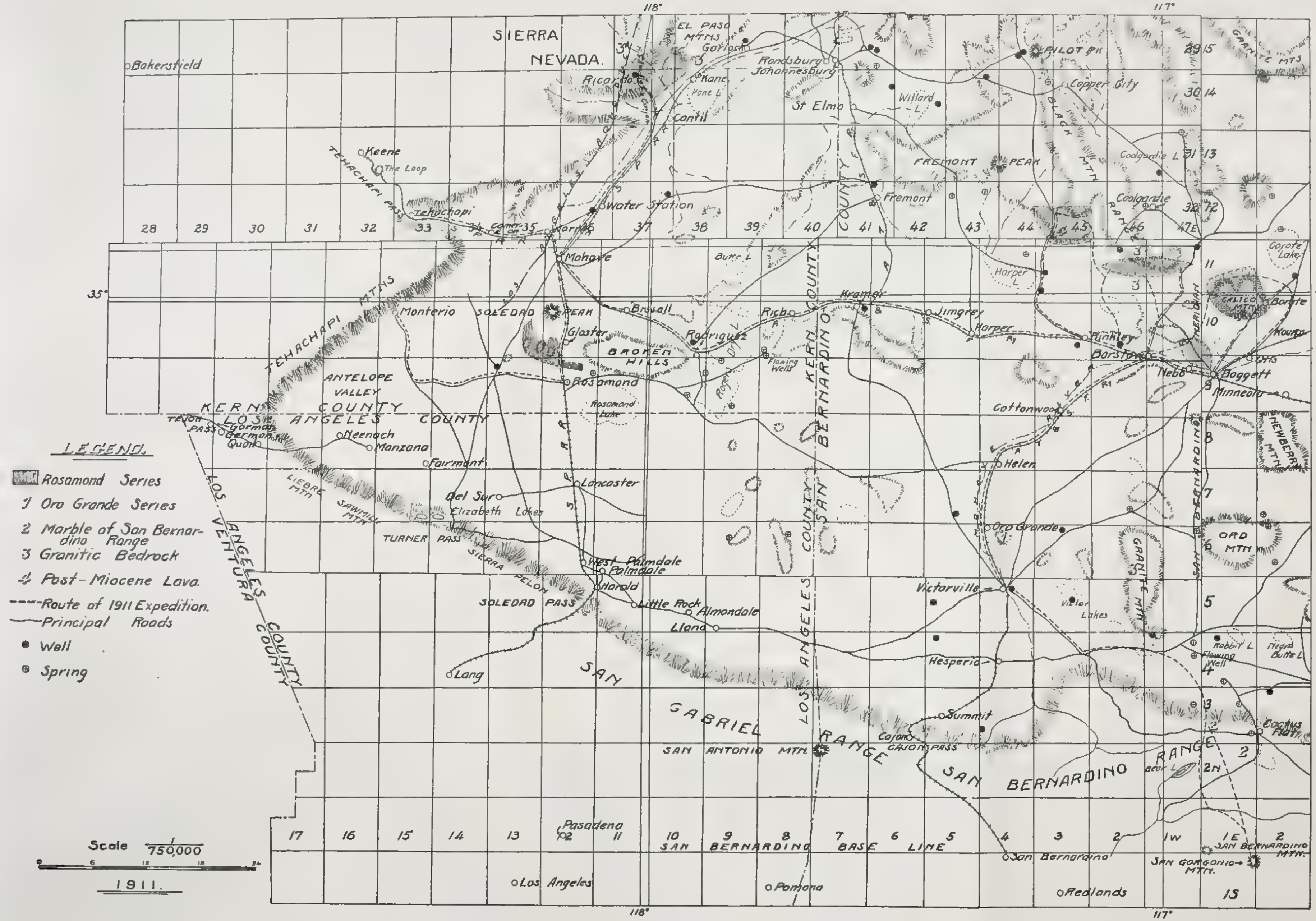


SIERRA NEVADA
EL PASO MTNS
Bakersfield
Garlock
Randsburg
Johannesburg
Ricardo
Kane
Cantil
St Elmo
Willard L.
PILOT PK
Copper City
Keene
The Loop
TEHACHAPI PASS
Tehachapi
Water Station
Fremont
FREMONT PEAK
Coolgardie
BLACK MTN
Mohave
Butte L
Harper L
Coyote Lake
35°
TEHACHAPI MTNS
Monterio
SOLEDAD PEAK
Bissell
Rich
Kramer
Jimgrey
Harper
CALICO MTN
Barstow
Daggett
Minneola
Nebo
Gloster
BROKEN HILLS
Rodriguez
Flowing Wells
ANTELOPE VALLEY
Rosamond
Rosamond Lake
KERN COUNTY
LOS ANGELES COUNTY
SAN BERNARDINO COUNTY
Cottonwood
NEWBERRY MTN
TEJON PASS
Gorman
Neenach
Manzana
Fairmont
Helen
LEGEND
Rosamond Series
1 Oro Grande Series
2 Marble of San Bernardino Range
3 Granitic Bedrock
4 Post-Miocene Lava
Route of 1911 Expedition
Principal Roads
Well
Spring
LIEBRE MTN
SAWMILL MTN
Del Sur
Lancaster
Elizabeth Lakes
TURNER PASS
Oro Grande
ORD MTN
GRANITE MTN
West Palmdale
Palmdale
Harold
SIERRA PELONA
LOS ANGELES COUNTY
VENTURA COUNTY
Victorville
Victor Lakes
SOLEDAD PASS
Little Rock
Almondale
Llano
Rabbit L
Negro Butte L
Flowing Well
Hesperia
Lang
SAN GABRIEL RANGE
Summit
Cactus Flat
Cajon
CAJON PASS
SAN ANTONIO MTN.
SAN BERNARDINO RANGE
Bear L
Pasadena
SAN BERNARDINO BASE LINE
San Bernardino
SAN BERNARDINO MTN.
SAN GORGONIO MTN.
Los Angeles
Pomona
Redlands
118°
117°
Scale 1/750,000
1911.

Although the expedition was made primarily for the purpose of collecting vertebrate fossils for a study of the extinct mammalian fauna of this region, and the notes on the geology are consequently very fragmentary, it is hoped that the geological observations may be of some interest. The value of the results is very considerably lessened because of the lack of a suitable map, and therefore the locations and distribution given for the various rock members are only approximately correct. A detailed petrographic study of the rock specimens will probably be made at a later date. The route followed and the localities visited during the reconnaissance are shown on the accompanying sketch map[2] (pl. 34).

LOCATION AND BOUNDARIES OF THE MOHAVE DESERT

The Mohave Desert region comprises the extreme southwestern portion of the Great Basin. It lies entirely within the State of California and includes within its limits portions of the four counties of San Bernardino, Inyo, Kern, and Los Angeles. Its boundaries on the northwest are the southern end of the Sierra Nevada Mountains and the Tehachapi Range; on the southwest are Sawmill Mountain, Liebre Mountain, the Sierra Pelon, with their southeastern continuation to the head of the Santa Clara River, and the San Gabriel Range; on the south are the San Bernardino Range and the Colorado Desert; on the southeast the natural boundary is the divide between the drainage tributary to the Gulf of California and the interior drainage of the Great Basin. The eastern and northern boundaries are difficult to fix, for there the Mohave Desert merges into the Great Basin proper with no marked drainage divides or high bounding ranges. The northwestwardly directed Piute Range, just inside the California border, may perhaps best be chosen as the eastern boundary, north of the divide of the Colorado River drainage. The northern limits of the Mohave Desert will be given as an east-west line connecting Castle, High, and Clark's

[2] For a map giving approximate areal distribution of the rocks in a portion of the area herein discussed the reader is referred to Mr. O. H. Hershey's "Geological Reconnaissance Sketch Map of Southern California," Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, pl. 1, 1902.

peaks, near the Nevada line, and running through Leach's Point and Burnt Rock Mountains to El Paso Peak, north of the mining camps of Randsburg and Johannesburg. That the eastern and northern boundaries as thus outlined are given not without a measure of reason is shown by the fact that they define the limits between the northern Great Basin region of markedly parallel mountain ranges and the southern Mohave Desert region of lower ranges without notable parallel arrangement.

METAMORPHIC, PLUTONIC, AND VOLCANIC ROCKS OLDER THAN THE UPPER MIOCENE

The oldest rocks encountered in the region of the Mohave Desert were two series of metamorphosed sediments: the one exposed in the sharp hills east of Oro Grande station on the Atchison, Topeka, and Santa Fe Railway; the other outcropping in the northern portion of the San Bernardino Range, in the northwest quadrant of the San Gorgonio Atlas Sheet of the United States Geological Survey. Plutonic rocks of a general granitic composition intruded these two series of metamorphics and outcrop in many places in the Mohave Desert. The eroded surfaces of the plutonics are covered by lava flows in the vicinity of the town of Barstow. A much altered schist and gneiss, which has been referred to the Archean by Hershey,[3] outcrops just north of the Mohave River northwest of Barstow, flanking on the south a granitic range.

THE ORO GRANDE SERIES

A series of marbles, quartzites, and slates, which have already been described by Hershey,[4] is given this name because of the proximity of its outcrop to Oro Grande station, which is situated less than a mile west of the western limit of the exposure. The quartzite is well cemented and exhibits planes of cleavage. Two varieties of marble were noted, one cream-colored with very coarse calcite crystals and the other with finer crystals and

[3] Some crystalline rocks of southern California, Am. Geol., vol. 29, pp. 286–287, 1902.

[4] *Op. cit.*, pp. 287–289.

alternate white and gray bands. The slates are micaceous, probably muscovitic, with very good cleavage into thin plates of large dimension, and probably form thin bands or lenses in the marble. The metamorphic series is tilted and faulted, and intruded by granitic rock with apophyses of orthoclase-muscovite pegmatite containing small dark-red garnets. Save the garnet, which was noted only in the pagmatite, no characteristic contact-metamorphic minerals were found. The series has been correlated by Hershey on purely lithologic grounds with the Lower Cambrian strata of Inyo County, California.

BASEMENT ROCKS OF THE SAN BERNARDINO RANGE

A large body of altered limestone, in which characteristic contact-metamorphic minerals have been developed, has been intruded by granitic rock in Furnace Cañon, in the northwest corner of the San Gorgonio Atlas Sheet. Two masses of the intrusive are connected by a dike varying from several hundred down to one hundred feet in width, which is more finely crystalline at its borders than in the middle, and can be easily traced across the slopes by its light brown weathered outcrop. Masses of tremolite, with fibers varying in size from several inches in length down to minute needles, are extensively developed in the limestone hundreds of feet from the intrusive contact. This mineral is especially abundant in the vicinity of the Wild Rose mine, in Wild Rose Cañon, a tributary of Furnace Cañon, where it makes up the greater part of the rock. The minerals cyanite, epidote, chlorite, chalcopyrite, and specularite were noted close to the intrusive contact. Copper was found in very small lenses containing the original mineral chalcopyrite, in places secondarily enriched to chalcocite, with azurite and chrysocolla, minerals of the zone of surface oxidation. Another body of contact-metamorphosed limestone was noted in Upper Holcomb Valley.

Other metamorphic rocks of the San Bernardino Range comprise argillaceous limestone with imperfect slaty cleavage, schists, and gneisses. The intrusive rocks found probably all belong to the family of granites, varying in texture from rather fine-grained dike rocks to very coarse-grained plutonics. A very coarse porphyry, with flesh-colored orthoclase phenocrysts as

large as two inches in long diameter, outcrops on the north wall of the Santa Ana River Valley one mile north of The Pines, along the trail from Seven Oaks to Bear Valley, Sec. 5, Twp. 1 N, R. 1 E of the San Bernardino Base and Meridian lines. San Gorgonio Mountain, the summit of the San Bernardino Range, is composed of granitic rock and gneiss.

GRANITIC BED-ROCK OF THE MOHAVE DESERT AND CONTIGUOUS RANGES

The southern slopes of Granite Mountain, north of the wagon road from Victorville to Rabbit Springs, are composed of a granitic rock exhibiting the exfoliation characteristic of rocks of this general composition everywhere in the desert. Granitic rocks are also exposed in the vicinity of the town of Victorville, where the Mohave River has cut a narrows through them. They also outcrop in the ranges northeast, north, and northwest of Barstow, where at least a part of them are granodiorites, are crossed by the Southern Pacific Railroad between Rosamond and Mohave, are found in the Tehachapi Mountains west of Tehachapi Pass and at the pass, in the Sierra Nevada east of the pass, and east of Red Rock Cañon in the southerly spur of the El Paso Mountains which flank the Sierra Nevada on the south. These rocks vary considerably in color, composition, and texture and are cut rather commonly by pegmatite and aplite dikes.

LAVAS PERHAPS EARLIER IN AGE THAN UPPER MIOCENE

A lava flow of very basic andesite or of acid basalt overlies granitic rock and underlies the basal beds of the Rosamond Series north of Barstow. Another lava, called by Gilbert[5] an ''orange, massive, subspherulitic rhyolite,'' rests on a granitic rock in Red Rock Cañon, on the southern spur of the El Paso Range. Lindgren describes a rhyolite, upon which the Rosamond Series is deposited, in the Calico Mountains. These lavas may belong to the general period of the Rosamond Series, although their weathered and eroded surfaces indicate that they are very likely older.

[5] Geogr. and Geol. expl. and Surv. west of 100th merid., vol. 3, pp. 142–143, 1875.

THE ROSAMOND SERIES OF UPPER MIOCENE AGE

DEFINITION AND DISTRIBUTION OF THE SERIES

Hershey gave the name Rosamond Series in 1902[6] to a succession of rocks which he characterized as being mainly rhyolitic in composition. The type locality is north and northwest of Rosamond station on the Southern Pacific railway, near the north side of Antelope Valley, and mainly to the west of the railroad between Rosamond station and the town of Mohave. His type section, comprising 1650 feet of strata, is given as follows, beginning with the base:

Type Section of the Rosamond Series near Rosamond Station

	Thickness.
Granite.	
1. Coarse and fine white sandstone, composed of granite debris and rhyolitic tuff, thin-bedded, regularly stratified and dipping westerly at angles of 10° to 20°	500 ft.
2. Bright, light red, stratified sandstone containing granite debris, some cobbles and boulders (water worn) of granite and many angular and subangular fragments of white tuff	50
3. Light yellow tuff mainly of rhyolite with an occasional pebble of granite; roughly stratified and dipping southerly	200
4. Massive dark red lava (apparently rhyolite); varies much in thickness, averaging about	100
5. Light greenish and yellow rhyolite tuff, coarse in layers; contains abundant and large angular fragments of the underlying red lava and an occasional pebble and small boulder of granite; roughly stratified and dips southerly 10° to 30°	400
6. White rhyolite, brecciated in layers	300
7. Light brown coarse sandstone; much granite debris and rhyolite; occurs in limited patches capping knolls	100

Hershey finds the series in a low mountain four miles west and one mile north of Rosamond, and at Willow Springs Mountain, two miles farther northwest. The latter mountain he regards as the site of one of the rhyolite volcanoes.

This volcanic belt seems to be represented in isolated patches along a line trending nearly due west along the northern border of Antelope Valley to its extreme western end. The purple and white lavas occurring in patches faulted down into the granite along the southern base of

[6] Am. Geol., vol. 29, pp. 365–370, 1902.

the Tehachapi Range near Gorman's station are on this line, are of similar composition and general appearance and doubtlessly belong to the same series. They go under the Upper Pliocene sandstone near Gorman's station. The borax mines west of Fraser Mountain seem to be in connection with another patch of them. Probably many other isolated areas will be found in the southern Coast ranges (pp. 366–367).

The Rosamond, according to Hershey, is found in the low mountain three miles south of Mohave, where the Exposed Treasure mine is located; in Soledad Peak, four miles south of Mohave; in many of the hills near the Santa Fe railway, five to seven miles southeast of Mohave; in Castle and Desert buttes, several miles north of Rogers dry lake; and in a narrow belt, rarely over several miles wide, trending eastwardly across Mohave Desert north of the line of the Santa Fe railway to beyond the town of Daggett. He suggests that the series also outcrops near Randsburg and for unknown distances east and south of Daggett. He includes within the series the sharp hills of lava outcropping in the Mohave River Valley in the vicinity of Barstow, and just northwest of Daggett he represents it as exhibiting the following phases:

1. Massive pink lava; appearance on casual survey much like andesite, but on close inspection with a hand microscope it seems as acid as some rhyolites.
2. White and purplish rhyolite; slightly porphyritic, with flow structure well developed so as to weather out with the appearance of a stratified formation, thin-bedded and highly tilted.
3. Breccia-conglomerate of lava and granite fragments.
4. Red sandstones and red shales.
5. Stratified fine and coarser tuffs of dark red color, tilted at a high angle.
6. Light red beds of coarse debris of pink granite, lava, etc.
7. A coarse, roughly stratified dark-red tuff containing fragments of black lava.

The last bed is very thick. Its general appearance is like the red tuffs of the Escondido series. Indeed all the members from No. 3 to No. 7, inclusive, are strongly suggestive of the Escondido series. They dip away from, and seem to rest unconformably upon the massive rhyolites which are typically Rosamond. This only confirmed a suspicion which I had before that the Rosamond and the Escondido series are of about the same age, but that the former is slightly the older and furnished the material for the fine-textured, supposed rhyolite tuff stratum under the basic lava of Tick Cañon.*

* Tick Cañon is tributary to the Santa Clara River and this locality is about four miles north of Lang station on the Southern Pacific railroad.

Remnants of a later series occur in Mohave River valley at several points, notably along the railroad about one and one-half miles east of Barstow. The following section, in descending order, of a bluff just north of the railroad, is typical of the series:

Type-Section of Barstow Series near Barstow

1. Stratified hard brown material due to arid conditions, but composition not determined; persistent stratum over a considerable area	20 ft.
2. Yellow and light gray silt	4
3. Stratified fine gravel and sand of dull red color and containing red lava fragments	15
4. Structureless bed of white tuff with angular and subangular fragments of various other rock species embedded in it	20
Total	59 ft.

This formation is extensively developed on the low hills on the north side of the valley between Barstow and Daggett. It is thin, overlies unconformably the earlier series, and remains generally in a horizontal position, but has been extensively eroded. It is a valley formation made under arid conditions. In a small railway cutting near the bluff where the above was taken, this series is locally much broken up and overlaid unconformably by 20 feet of the nearly horizontal, roughly stratified, subangular gravel and clay which seem to form low Quaternary ridges on the south (pp. 368–370).

The Rosamond Series was examined in five different localities during the recent reconnaissance. These localities comprise: (1) an area north of Barstow, in Township 11 N, Ranges 1, 2, and 3 W of the San Bernardino Base and Meridian lines; (2) a portion of the Calico Mountains north of the towns of Daggett and Otis, in Townships 10 and 11 N, Range 1 E; (3) Black Mountain, Townships 31 and 32 S, Ranges 44 and 45 E of the Mount Diablo Base and Meridian Line; (4) an area between Rosamond and Mohave in Townships 9 and 10 N, Ranges 12 and 13 W, and Township 11 N, Range 12 W of the San Bernardino Base and Meridian lines; and (5) in the region centering about Ricardo postoffice, in Red Rock Cañon, on the southern spur of the El Paso Mountains, in Townships 29 and 30 S, Ranges 36 and 37 E. In all these localities the series has a general east-west strike.

In the above localities the Rosamond is mainly a sedimentary series, with only a subordinate amount of both acidic and basic lava flows. The sediments are mainly breccias, with fragments

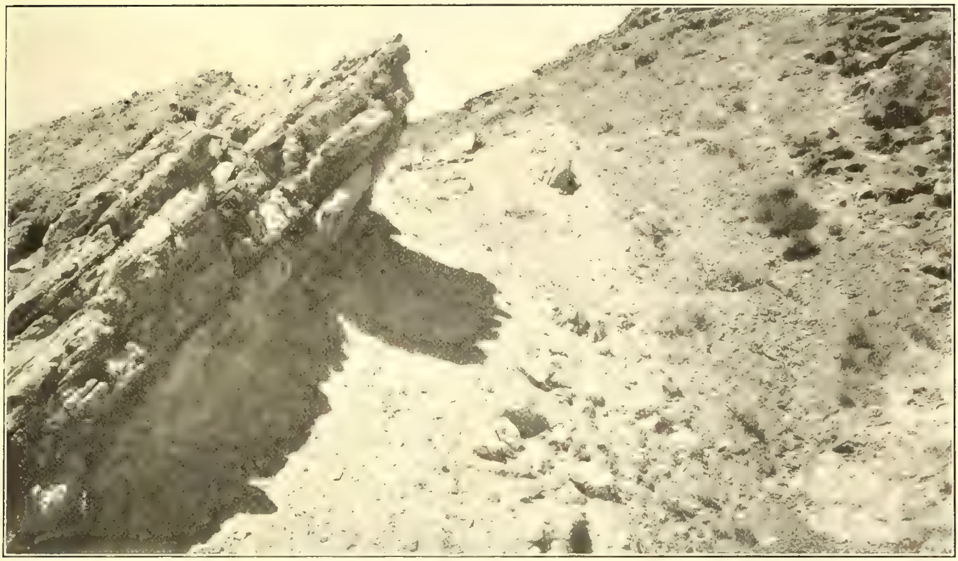
of granitic materials and lavas and matrices of finer arkoses, volcanic ash, and chemical precipitates. Tuff-breccias, finer tuffs, and shales and mudstones with interbedded layers of gypsum, calcium carbonate, and borax minerals occur in subordinate amounts. Conglomerates of water-worn boulders are of rather rare occurrence.

ROSAMOND EXPOSURE NORTH OF BARSTOW

The Rosamond here attains its maximum known development both in thickness and diversity. The approximate thickness of the series cannot be much less than a mile, although faulting has rendered difficult the determination of the exact thickness. In this exposure there are at least five mapable units, but not all of the five have yet been found in any other single locality.

Basal Breccia Member.—The base of the Rosamond is everywhere marked by an erosion unconformity with a basal breccia resting on weathered surfaces of granitic rocks and lavas (pl. 35A). At the base of the south limb of the Barstow syncline a distinct basal breccia of mapable thickness occurs, resting on the eroded surfaces of both granodiorite and a basic andesite or acid basalt, and containing fragments of both of these rocks. The member is mainly dark brick-red in color and at least several hundred feet thick, although the displacements caused by two strike faults makes its exact thickness uncertain. The fragments are mostly angular or subangular, but some rounded pebbles and boulders which probably owe their form to exfoliation, as indicated by their rough surfaces, are found. The fragments are rather small, ranging up to six inches in diameter. The matrix is mainly arkosic, being largely disaggregated fragments of quartz and feldspar derived from the granodiorite. A basal breccia of this same type was found resting on granitic rock at the base of the north limb of the syncline, at the northwest end of the exposure, but farther east the basal beds contain such a large proportion of volcanic ash that they may more appropriately be included in the next member.

Tuff-breccia Member.—(Pl. 35B.) This differs from the basal breccia member in being mainly composed of finer fragments, in generally containing less granitic material, and in having in



A. Contact of basal breccia member of Rosamond Series with basic andesite or acid basalt, north limb of Barstow syncline. The lighter portion of the lava next the contact is more weathered than the darker portion to the right.

B. Tuff breccia member of Rosamond Series resting on granitic rock with erosion unconformity at base of north limb of Barstow syncline. The graded profile of the granitic rock surface at the left and the strike valley in the center should be noted.

general a much larger proportion of volcanic ash in its matrix. It does not weather into badland forms, but produces rounded hills or cliffs of rather bold, shaggy outline. It is considerably over a thousand feet in thickness in the north limb of the Barstow syncline, with its upper limit defined by an unconformity of unknown extent. The member is made up of highly variegated thick bands of whitish, cream-colored, pink, red, lavender, purple, brown, and green tuff-breccia. The colors are very bright and their frequent alternations present some striking contrasts. The breccia fragments are of white and variously colored tuffs and lava with colors ranging in almost all gradations from white to black. The lava fragments exhibit various degrees of alteration and in some fragments flow structure was noted. Locally fragments of granitic rock occur and the base of the member rests upon granitic rock.

Fine Ashy and Shaly Tuff Member.—(Pl. 36A.) This member outcrops in the south limb of the Barstow syncline where its southern limit is defined by a strike-fault of unknown displacement which separates it from the basal breccia member. The lower beds are mainly composed of a greenish-gray rather fine unconsolidated ash, with thin, more resistant layers. A single specimen of *Planorbis,* a fresh-water gasteropod at the present day inhabiting ponds and lakes, was found by Professor John C. Merriam near the base of the member. Platy selenite and clay ''mud-ball'' concretions were found abundantly in the thinner-bedded less-resistant lower portion. The clay and ironstone concretions resemble very tuberous potatoes; they measure from one to two inches in long diameter and are flattened parallel to the bedding. The more resistant ironstone is strewn on the slopes, giving them a brown or deep purple color when viewed from a distance. The weathered surfaces of the beds have a very marked soft, velvety appearance and the surface film is marly, probably because of the deposition of soluble salts leached from the underlying beds.

Near the top of the member is a considerable thickness of dark brownish-gray compact mudstone, with rather massive bedding and apparently formed of fine clay. The surfaces of this mudstone along cracks and joints are covered with a thin film

of shiny black oxide of manganese. Thin interbedded layers of impure fibrous gypsum, ranging up to about an inch in thickness, with the long axes of the mineral prisms at right angles to the bedding planes, occur in the mudstone. At the top of this mudstone a few small pieces of lignite were found. The member has a thickness of approximately five hundred feet.

Resistant Breccia Member.—Above the mudstone the beds rapidly become coarser and more resistant. This member is about intermediate in composition between the basal breccia and the tuff-breccia members. It is in general coarser than the tuff-breccia member and, unlike it, it weathers into badland forms with perpendicular faces and sharp angles. In texture it resembles the basal breccia member, but differs from that member in having a larger percentage of volcanic ash. It is characteristically a series of beds composed of coarse arkoses. It outcrops in the trough of the Barstow syncline, overlying in normal succession the fine ashy and shaly tuff member in the south limb of the syncline, while in the north limb its northern limit is defined by a fault. Between this fault and the unconformity marking the upper limit of the tuff-breccia member is several hundred feet of very coarse granodiorite breccia, containing angular boulders with sizes varying up to four feet in diameter, with a matrix of arkosic material composed of disintegrated granodiorite fragments. So well consolidated and so homogeneous in its material is this breccia that in places care must be used to determine its secondary fragmental origin.

The resistant breccia member is approximately 1000 feet in thickness, although, again, its full thickness cannot be determined because of the strike-faults which cut its strata on both sides of the trough of the syncline. It is greenish and grayish in color in its lower portion, but becomes brownish and reddish higher up. The colors are softer and of more subdued shades than those of the tuff-breccia member. Angular granitic boulders two to three feet in diameter are common. The beds higher up become in general successively finer than those in the lower half. Near the middle of the member in the south limb of the syncline were found remains of a merycodont, a horse, and a large camel in a bed of greenish-gray soft ash, at least fifty feet

A. Exposure of fine ashy and shaly tuff member of Rosamond Series in the south limb of syncline, showing characteristic weathering of the unconsolidated beds. At the right with a fault contact are strata of the basal breccia member. On the left in normal succession are the basal beds of the resistant breccia member. The capping is of later alluvium.

B. Fossiliferous tuff member of the Rosamond Series exposed in the trough of the Barstow syncline, near the west end of the exposure. The badlands are characteristic of the less consolidated portion of the series. Through the middle in the middle distance runs the indurated basal layer of the later alluvium, which here dips 2° to the southwest.

thick. This is the lowest horizon at which mammalian fossils were found.

Fossiliferous Tuff Member.—It is as yet difficult to define the limits of this the highest member of the Rosamond Series in the Barstow locality. Only what is probably a remnant of the lower portion of the member has been preserved from erosion. There is a gradual gradation from the coarser and more resistant beds of the resistant breccia member into the overlying finer tuffs of the fossiliferous member, but at the contact of the two there is an alternation of layers of coarser and finer material. In one of the lower finer layers the mammalian remains mentioned above were found. Some coarser layers occur in the fossiliferous tuff member, and the fragments of a part of these show the effects of water wear.

This member is made up essentially of light yellowish-brown and light bluish-gray beds of comparatively unindurated material. The light yellowish-brown beds are composed mainly of fine granitic arkose with interstratified layers of coarser granitic and lava breccia. The grayish beds are mainly finer in texture and contain a larger percentage of volcanic ash, as well as a large majority of the mammalian fossils found. Some finer gray layers are interstratified with the lower light-brown portion. The lower portion and the overlying mantle of alluvium have the same structure, texture, and composition of ill-assorted material, their color is very nearly the same shade, although that of the fossiliferous tuff member is a trifle lighter; and although this member may be said to possess in general a higher degree of induration than the more superficial capping of alluvium, the frequent absence of well-defined bedding-planes in the older beds make their separation from the younger debris mantle locally a matter of considerable difficulty. Some of the less indurated layers in the lower portion of the fossiliferous member are very susceptible to gully erosion. The major drainage courses in the upper light-gray member are transverse to the strike of the beds, but the tributary gullies show a notable arrangement parallel to the strike. The upper light-gray member contains many local, comparatively resistant bands which may or may not be made up of coarser material.

The lower member of yellowish-brown beds has in places layers of coarser angular granitic boulders. A typical layer of the finer breccia, which occurs interbedded with the still finer material which makes up the greater mass of this lower portion, contains angular particles up to four inches in diameter of granitic rock and red, white, and brown lavas, with a coarse, gritty matrix of disaggregated fragments of quartz, feldspar, and mica. Some of the lava particles are porphyritic, with phenocrysts of orthoclase, mica, and quartz. Aside from this rhyolite, there are lavas of other composition.

The fossiliferous tuff member outcrops in the very middle of the Barstow syncline where the topmost exposed layer, of a light gray fine conglomerate, contains many isolated mammalian bones. It is underlain here by the uppermost beds of the resistant breccia member, the whole being faulted on both sides against lower beds of the resistant breccia member. The chief exposures of the fossiliferous member are found at the western end of the outcrop of the Rosamond Series in the Barstow locality, where the strata are folded into a syncline and displaced by several strike faults. The general aspect of the beds may be seen in the accompanying illustrations (pls. 36B and 37A).

The organic remains found comprise ungulate and carnivorous mammals of plains-living cursorial types, several species of fresh-water gasteropods, and a few fragments of silicified and lignitized wood.

Structure of the Rosamond Series in the Barstow Locality.—The general structure in this locality is synclinal (pl. 37B) and

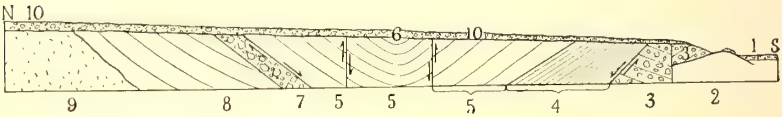
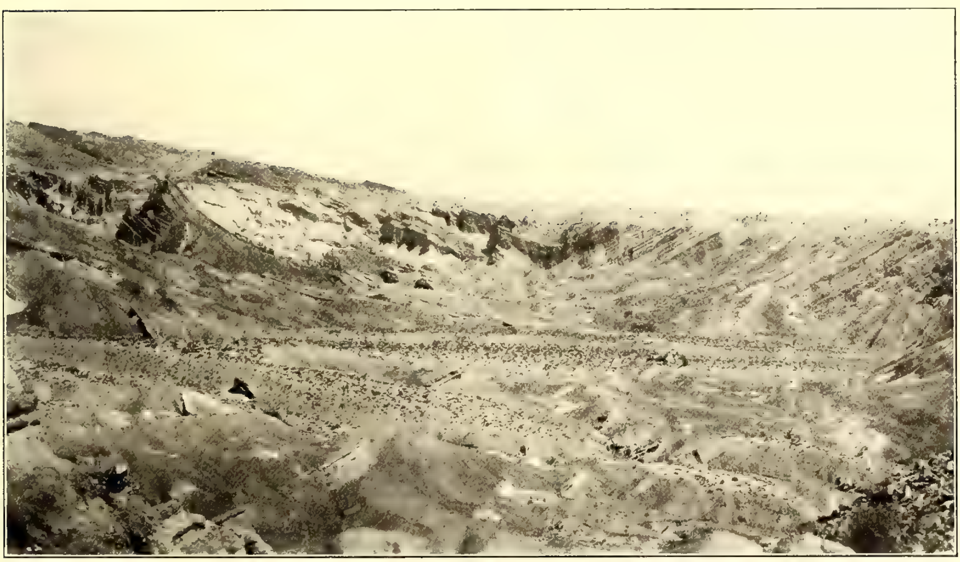


Fig. 1. North-south section through the center of the minor axis of the Barstow syncline. Not drawn to scale, but the length of the section is approximately three miles. (1) Basin alluvium. (2) Basic andesite or acid basalt. (3) Basal breccia member. (4) Fine ashy and shaly tuff member. (5) Resistant breccia member. (6) Lowermost beds of fossiliferous tuff member. (7) Coarse granodiorite breccia, separated from (8) by an unconformity. (8) Tuff-breccia member. (9) Granodiorite. (10) Unconformable mantle of alluvial debris, dipping toward basin at a uniform angle of 2°.

A. Lower strata of fossiliferous tuff member of Rosamond Series in north limb of Barstow syncline and near the west end of the exposure. Remains of horses were found in considerable abundance in the lighter layers striking through the center of the picture.



B. Strata of the resistant breccia member of the Rosamond Series in the trough of the Barstow syncline, looking east. Capping of later alluvium and synclinal basin of erosion also shown.

a section through the center of the minor axis of the Barstow syncline is given in fig. 1. Faults of various degrees of displacement are fairly common. All noted were approximately parallel to the general east-west strike, and were of the normal type, although the verticality of many of the fault-planes hint of the possibility of some upthrusting. From the relations of the faults to the folding it is probable that the folding of the strata into the syncline preceded the period of faulting. The structural relations in plate 38A suggest that a monocline was first formed which was afterwards faulted on both sides.

THE BLACK MOUNTAIN ROSAMOND EXPOSURE

The Black Mountain locality is separated on the east from the Rosamond exposure north of Barstow by an alluvium-covered basin, near the middle of which strata lithologically similar to those of the Rosamond Series are exposed in the bank of an arroyo. Three members were noted in the Black Mountain section which correspond closely to members of the Rosamond Series in the Barstow syncline. These will be herein described under the names applied to strata in the locality north of Barstow, although the resemblances between the beds in the two exposures are merely lithologic and no certain correlations can be made.

Tuff-breccia Member.—The rocks exposed in the sharp conical peaks north of Black Mountain and near the head of Black Cañon, in the vicinity of the American Opal Company's prospect, contain layers of interbedded lavas with flow structure. Considerable agate, chalcedony, and opal occur as cavity- and fracture-fillings in the tuff-breccia. In other respects the beds resemble those of the tuff-breccia member in the Barstow syncline and are dipping in the same direction. Their relations to the other members in the Black Mountain locality are unknown, for they are bounded on the south by a fault which brings them in juxtaposition with beds referred to the fossiliferous tuff member.

Fine Ashy and Shaly Tuff Member.—Beds in every respect similar to strata referred to this member in the Barstow syncline outcrop at the foot of Black Mountain on the northwest, on the

western side of Black Cañon, where they have been folded into a small dome. The base of the member is not exposed here. At the top of the member is a layer of basalt which gradually thins to the northward, finally becoming attenuated to a knife-edge and disappearing on the north side of the dome. Although this basalt may possibly be a phacolite,[7] the lack of evidence of contact-metamorphism of the overlying beds, while the underlying strata are baked a brick-red at the lower contact; the large vesicles in the basalt which are filled with amygdules of chalcedony and agate; and the fact that the basalt layer does not cut across bedding planes, but is in perfect accordance with the bedding of the contiguous strata, apparently indicates that the basalt is a contemporaneous lava flow.

Upper Member of Breccia and Tuff.—The ashy and shaly tuff beds are conformably overlain by a coarse granitic breccia, with an arkosic matrix, which is light pink in color and very poorly cemented. The beds are finer higher in the succession, the materials grading into fine gravel and volcanic ash. Near the fault which separates it from the ash-breccia member were found a few indeterminable fragments of bones.

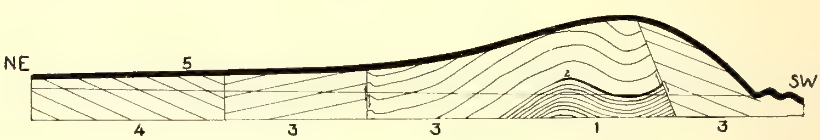
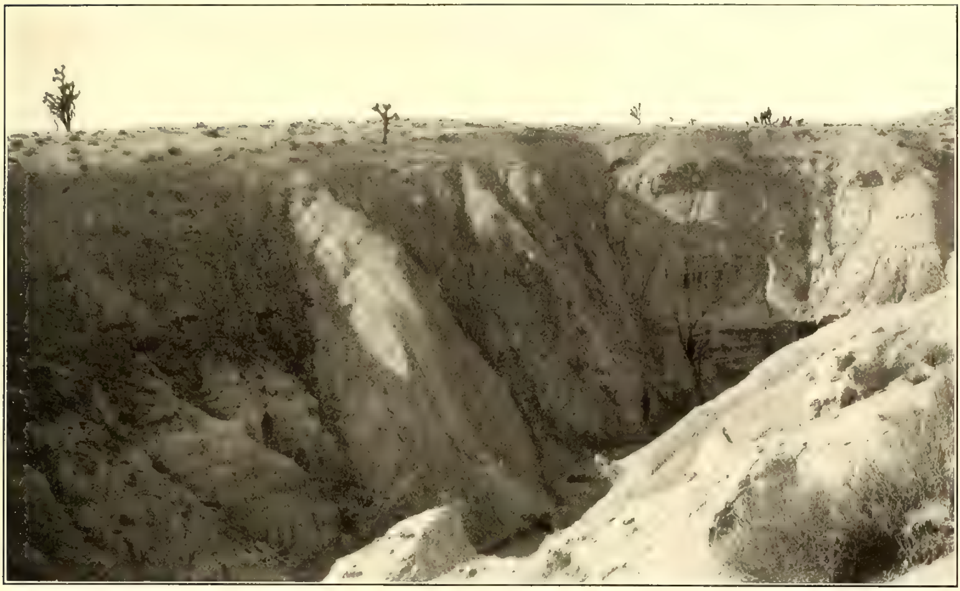


Fig. 2. Cross-section of the Rosamond Series at Black Mountain. Length of section about five miles. The profile of Black Cañon is also represented. (1) Fine ashy and shaly tuff member. (2) Basalt layer. (3) Upper member of breccia and tuff. (4) Tuff-breccia member. (5) Folded basalt flow forming surface of Black Mountain.

Structure of the Rosamond at Black Mountain.—A northeast-southwest section of the Rosamond Series is given in fig. 2. The beds have been subjected to a minor amount of lateral compression. A minor fault with tilting is shown in plate 38B. On the northern side of the dome a red stratum dipping

[7] A phacolite, according to Harker, is a concordant intrusion which occupies crests and troughs of folds, and which disappears entirely or is present only in very attenuated thickness in the flanks. See "The natural history of igneous rocks," p. 77, 1909.



A. Faults caused either by tension or compression in the fossiliferous tuff member of the Rosamond Series near center of exposure in Barstow syncline. Apparently a sharp monocline has been faulted on both sides.

B. Faulting in Rosamond strata in Black Cañon.

20° to the south has been displaced by a transverse fault, with a stratigraphic throw of fifty feet and a horizontal displacement of 200 feet. A stereogram of this fault is shown in figure 3.

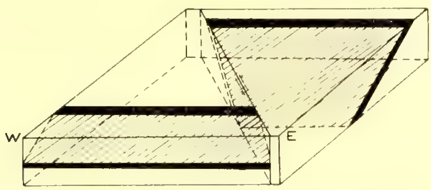


Fig. 3. Stereogram of fault on south side of dome, west of Black Cañon. The stratigraphic throw is 50 feet, while the horizontal displacement is 200 feet.

ROSAMOND BEDS IN THE CALICO MOUNTAINS

The first account of the geology of the Calico Mountains was given by Lindgren, who includes in his paper a sketch map and cross-section.[8] Lindgren recognized the salient features of the geology, representing the base of the Rosamond Series as resting on rhyolite, that the series was sedimentary and made up of coarse granitic and rhyolitic materials at the north and of finer sandstones, tuffs, and clays at the south, and that the beds in the southern portion of the exposure had been very closely folded and faulted into juxtaposition with a flow of hornblende andesite, while the more massive beds farther north had been tilted but not strongly folded. Storms[9] confirmed Lindgren's observations and appears to have been the first to advocate a lacustrine origin for the borax beds in the tuffs, sandstone, and clays. Campbell,[10] in a reconnaissance report on the borax deposits of Death Valley and Mohave Desert, has the following to say concerning the Borate locality:

> The principal deposit of boron salts occurs at Borate, about 12 miles north of Daggett, in the vicinity of the old Calico mining district. The mineral found here is borate of lime, or colemanite, and it occurs as a bedded deposit from 5 to 30 feet in thickness, interstratified in lake sedi-

[8] The silver mines of Calico, California, Trans. Am. Inst. Min. Engrs., vol. 15, pp. 717–734, 1887.

[9] Report on San Bernardino County, 11th Ann. (1st Biennial) Rept. of the State Mineralogist, Cal. State Min. Bur., pp. 337–369, 1893.

[10] U. S. Geol. Surv., Bull. no. 200, 1902.

ments. These lake beds are composed of semi-indurated clays, sandstones, and coarse conglomerates, with interbedded sheets of volcanic tuff and lava. The rocks are severely folded, the axes of the folds lying in an east-west direction. The lake beds extend in the same direction across the mountains for a distance of about 8 miles. It has been supposed that these deposits probably continue westward under the Pleistocene drift of the desert, but there is no evidence at hand to prove such an assertion. In fact, the lake beds at Borate do not come down to the foothills of the mountain; they are cut off and infolded with the crystalline rocks of the Calico district. Lake beds are present west of Calico Valley, and a bed of colemanite has been struck in a shaft in this locality at a depth of 200 feet. Although the colemanite is interbedded with sand and clay, it is not coextensive with these strata. As a traceable bed it probably extends for a distance of a mile and a half; beyond this limit it is very thin, and in many places it is wanting in the section. At the Borate mine there are two outcrops of colemanite, either on parallel beds or on one bed that has been so closely folded as to give two parallel layers about 50 feet apart. The beds strike approximately east and west, and dip to the south from 10° to 45° . . .

Recently Keyes[11] has described the borax deposits and has contributed the important observation that a lava flow overlies the beveled edges of the tilted borax-bearing strata. This observation was confirmed during the recent reconnaissance.

Campbell describes the beds south of the Calico Mountains as follows:

From Stoddard Wells the road follows a direct course N 20° E until it emerges into the valley of Mohave River 5 miles west of Daggett. A belt of Tertiary rocks having a width of about 1¼ miles is crossed by the road 4 miles south of this bend. The rocks are composed generally of fine clay and sand, containing a large amount of gypsum and other salts. Several thick beds of limestone were noted, which appear to have been the result of chemical deposition. The lower beds are composed of fragmental material; but in the upper part of the series occur many lava sheets which preserve the beds in high, even-crested ridges. This belt of rocks extends in a nearly east-west direction. The strata have been gently tilted along an axis running in the same direction, so that they now dip to the north about 5°.

The ridge formed by these beds appeared to extend westward for a distance of only a mile or two, and then to die out in the even expanse of desert which presumably extends to Mohave River. Toward the east the lake beds extend indefinitely. The question of the relation of these beds to the horizontal strata west of Mohave River is most interesting, and an examination of the western end of the beds just described might throw light on the relative age of these deposits.

[11] Borax deposits of the United States, Trans. Am. Inst. Min. Engrs., no. 34, pp. 867–903, 1909.

Heavy deposits of gravel occur on the northern slope of the Tertiary ridge. They rest upon the lake beds in such a manner as to suggest that the northward slope of the surface is a structural feature due to the tilting of a block of strata in that direction. If that is true, these lake beds probably underlie the Mohave River Valley in this vicinity.

Tuff-breccia Member.—Tuff-breccia is widely exposed in the Calico Mountains, being found as a basement rock in the midst of the hills and exposed on the western flanks. The beds examined correspond closely in character with the strata of the tuff-breccia member in the Barstow syncline from which they are separated on the west by a narrow alluvium-covered basin. Chalcedony and opal form seams and irregular masses which are rather abundant just north of the southeast corner of Sec. 36, Township 11 N, Range 1 E. Milky white opal forms botryoidal and mammillary masses incrusting chalcedony, and is found as layers in chalcedony, tuff-breccia, and lava. Hyalite was found as an incrustation upon opal, while quartz was the last mineral to be formed in the cavities. The tuff-breccia probably underlies the Borate member.

Borate Member.—At the mouth of Wall Street Cañon, on the southwestern base of the Calico Mountains, there is a dark red volcanic breccia made up of large-sized boulders of red lava. This is followed toward the north by reddish, brownish, and purplish breccias resembling the resistant breccia member in the Barstow syncline. Next come strata resembling the fine ashy and shaly tuff member of the exposures north of Barstow, which are composed of whitish, light bluish-gray, light green, and light yellowish-brown soft velvety ashy beds with layers of "paper shale," mudstone, limestone, fibrous gypsum, and colemanite. Underlying these beds and conformable with them are dark brown, fine gravelly beds which show ripple marks. Below the latter the succession is uncertain because of the intense crumpling and faulting of the strata, but it is probable that the tuff-breccia member with intercalated lava flows is the next lowest stratigraphic member.

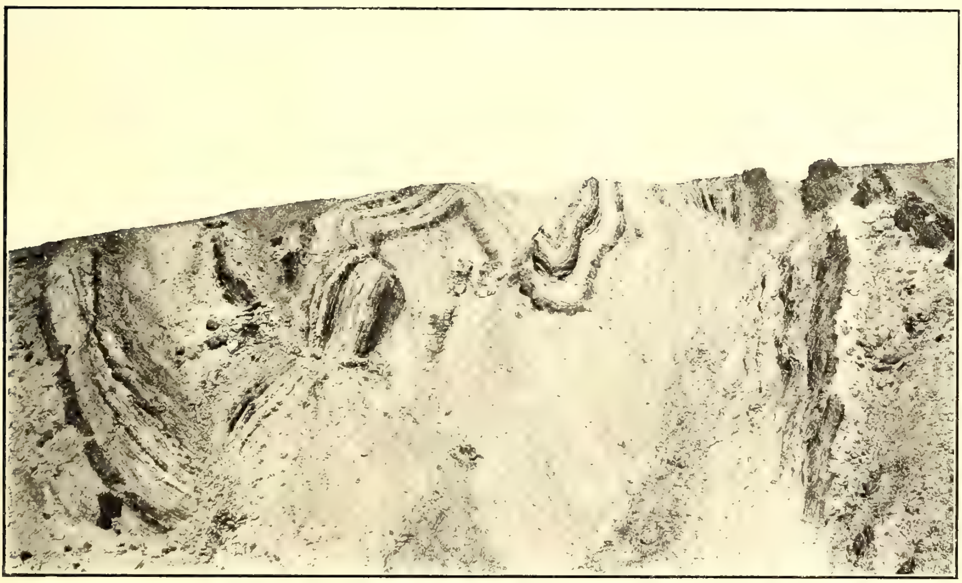
In the finer beds is found considerable black-banded chert. The darker brown, thicker, more resistant layers intercalated with the shales show rain prints and sun cracks. The thicker, more compact and ripple-marked strata of the borax-bearing

beds are limestone. The thin paper shales, of light green, gray, and white shades, contain nodules and thin layers of what seems to be fine-grained limestone. Some clayey concretions are also found in these shales, and interspersed are interbedded layers of fibrous gypsum and borax minerals, principally colemanite ($Ca_2B_6O_{11} + 5\,H_2O$); and these minerals also form nodules and lenses. Some of the rock superficially resembles a fine conglomerate, but it is perhaps more properly regarded as tuffaceous or oolitic. Cross-bedding is frequent in the thicker and harder layers.

The view is entertained that the Escondido Series mapped by Hershey north of the Mohave River, between Barstow and Daggett, is a portion of the Borate member. There is much lithologic resemblance in the two exposures, which are separated only by a narrow alluviated basin. The strata in both localities rest upon rhyolite and have been subjected to the same amount of deformation and erosion. Northeast of Barstow the beds mapped as Escondido lie upon granite and micaceous schist. The basal beds of the series are composed of heavy breccia and of rather fine arkoses of granite and schist, and of medium fine-grained sandstone. The beds are brown, red, green, and gray in color and dip in a southerly direction. They are cross-bedded. The quartz, granite, schist, and lava boulders at the base are angular to subangular in contour, ranging in size up to a foot or larger. The matrix is mainly made up of disaggregated crystals and of small pieces of lava, although all of the material of the boulders are represented. The lava is acidic, and the schist beneath the contact is very much altered and weathered. The beds are folded into anticlines and synclines.

North of the Mohave flood-plain, near the road on the north side of the river, limestone and chert beds dip southward. The beds are brown, red, and gray in color and contain veins, cavities, and incrustations of calcite, quartz, and other minerals. Strata of this nature locally outcrop in the Mohave Valley between Barstow and Daggett.

Structure of the Rosamond Series in the Calico Mountains.—The incompetent strata of the Borate member, or those which bend easily under stress or strain, have been intensely folded



''Appalachian structure'' in Borate member of Rosamond Series, near Borate, Calico Hills.

and overthrust, as will be apparent from the accompanying illustrations (pl. 39A and B). Locally the thin shales and interbedded borax layers have been closely crumpled. Less competent layers have crumpled under horizontal compressional stresses where more competent beds have fractured or remained undisturbed (pl. 40A). In this case it is clear that horizontal movement along bedding planes has occurred. A later faulting which has effected the strata of the Rosamond Series will be considered elsewhere in this paper (p. 368).

THE ROSAMOND SERIES IN THE TYPE LOCALITY AT ROSAMOND

Strata, composed mainly of volcanic tuff-breccia, with intercalated flows of both acid and basic lavas, and a subordinate amount of granitic breccia and bedded chert, rest on granitic rock with a thin basal breccia along the track of the Southern Pacific railroad about two and one-half miles north of Rosamond station. In the vicinity of the railroad and eastward as far as the west side of Rosamond dry lake the beds dip about 15° to the southward. But at the western end of the exposure the strike gradually changes from east-west to north-south and the dip from south to west. Hershey's type section was given on page 339.

The thinness of the granitic basal breccia, which is wholly absent in places, apparently indicates that locally at the time of deposition of the basal beds the granitic land mass was of rather low relief and even surface. The matrix of the basal breccia is volcanic ash. Immediately next the granite in places in the Rosamond locality, as well as locally in the Barstow syncline and east of Red Rock Cañon, is a pure white, fine-grained, compact, porous rock which is probably a leached volcanic rock.

Some four hundred feet above the base is an interbedded flow of red acidic lava exhibiting flow structure and containing obsidian, felsite, and dark gray perlite. Mammillary and botryoidal structures are very common in the interbedded lava. Below this lava the tuff-breccia is locally cemented by an opaline cement and in places contains seams and botryoidal masses of chalcedony, incrusted by opal. The lava of the breccia is apparently identical in composition, texture, and structure with that

in the flows. On the hill north of and above the first stamp mill west of the Southern Pacific track, and northwest of Rosamond station, is a red porphyritic lava with phenocrysts of quartz or sanidine and subordinately feldspar. In places this lava is also felsitic with flow structure and contains some light gray perlite.

At the northeastern end of that portion of the Rosamond exposure west of the Southern Pacific tracks is a fault with splendid examples of slickensiding. The beds here contain agate, chalcedony, opal, silicified wood and a considerable amount of bedded chert. About one-eighth of a mile farther west is a thin bed of highly vesicular basalt probably of not very great horizontal extent. Immediately over this basalt is a thin layer of green, rose, and brown agate, in which the green is interwoven with the other colors in very complex patterns. Amygdules of quartz, with crystals sometimes forming a comb-structure in the centers of the cavities, occur in vesicles and cavities of the basalt.

THE ROSAMOND SERIES IN RED ROCK CAÑON

The mouth of Red Rock Cañon is about twenty-five miles by rail north of the town of Mohave. The cañon drains a portion of the southern slope of the Sierra Nevada and just above its mouth cuts through a southwestern spur of the subsidiary El Paso Range. The Rosamond strata, which outcrop in Red Rock Cañon on both sides of this spur, were first described by Gilbert,[12] whose original account is here quoted in full:

> In the vicinity of Walker's Pass there is a long, low, detrital slope from the Sierra Nevada to the desert at the east, and the same exists thirty miles farther south. In the interval the slope is interrupted by the low, irregular El Paso Mountains, which appear to have risen, in part at least, since the establishment of the detrital slope. Red Rock Cañon, having a southeast course, intersects a southerly spur of the El Paso Mountains, and rises among detrital beds that lie between this spur and the Sierra Nevada. For two or three miles it cuts obliquely a series of beds dipping westward from the El Paso spur, at angles ranging from 15° to 30°. Fig. 56 gives a section normal to the strike, but based on notes taken along the oblique cutting of the cañon. No. 1 is a lightly cemented coarse sand or fine gravel, pale umber to ochre in color, and consisting of rounded grains of quartz, mica, feldspar, and divers volcanic rocks. Upward it is inseparable from the granite sand of the

[12] Geogr. and Geol. Expl. and Surv. W 100th Merid., vol. III, pp. 142 and 143, 1875.

Sierra slope. It does not cleave into strata, but the direction of bedding is conspicuous in the exposures, and different layers weather so unequally that the whole is carved into a series of escarpments, the faces of which are beautifully fluted by rain. The thickness exceeds 400 feet. Nos. 2 and 4 are basalts, 30 and 50 feet respectively in thickness. No. 3, 100 feet; No. 5, 200 feet; and No. 7, 100 feet, are like No. 1, but more coherent, the cementing material being insoluble in acids. No. 6, 100 feet thick, is a homogeneous, pale pink, volcanic tuff, containing all the constituents of the adjacent sands, with the addition of pumice and a definite matrix. No. 8 is a sand like No. 1, but well cemented by oxide of iron. No. 9 is an orange, massive, subspherulitic rhyolite, and No. 10, a massive fine-grained compound of hornblende, pyrite, and a feldspar. The two, whose correlation was not made out, constitute the spur of the range and wall the cañon for a half mile. Beyond them the sands are resumed (11) with the same dip, but their relation was not established. The line of section, produced eastward, would reach out on an open desert—that in which is the Desert Wells stage station.

The chief interest of the section lies in the close relationship of the sand beds to the intercalated tuff. The latter is a product of eruption, endowed with a light vesicular paste, and separable by no sharp line from typical lavas. The former is so closely affiliated to the tuff, on the one hand, and to the ordinary desert detritus on the other, that we are left in doubt whether it was transported and distributed by volcanic or by meteoric waters.

Fairbanks[13] was the next geologist to visit the Red Rock Cañon locality. He describes the sediments there as follows:

. . . On the northern slope of the El Paso Range, between Mojave and Owen's Lake, there is a series of beds of clays, sandstone, volcanic tuffs and interbedded lava flows. These are probably 1000 feet or more in thickness and extend over a considerable area between the El Paso range and the Sierra Nevadas. On the north and northeast they pass beneath Salt Wells valley and the wash from the Sierra Nevadas. They are finely exposed in Red Rock Cañon and about Black Mountain, the highest peak of the district. . . . The beds are tilted northward at an angle of 15°–20°. Remnants of strata of about the same degree of consolidation appear on the south side of the El Paso Range and dip in the same direction. This seems to indicate a tilting en mass of the range and adjoining country.

J. H. Smith[14] gave the name "Mojave Formation" to the sediments in Red Rock Cañon, basing the name on Fairbank's description, which is quoted above, and erroneously referring

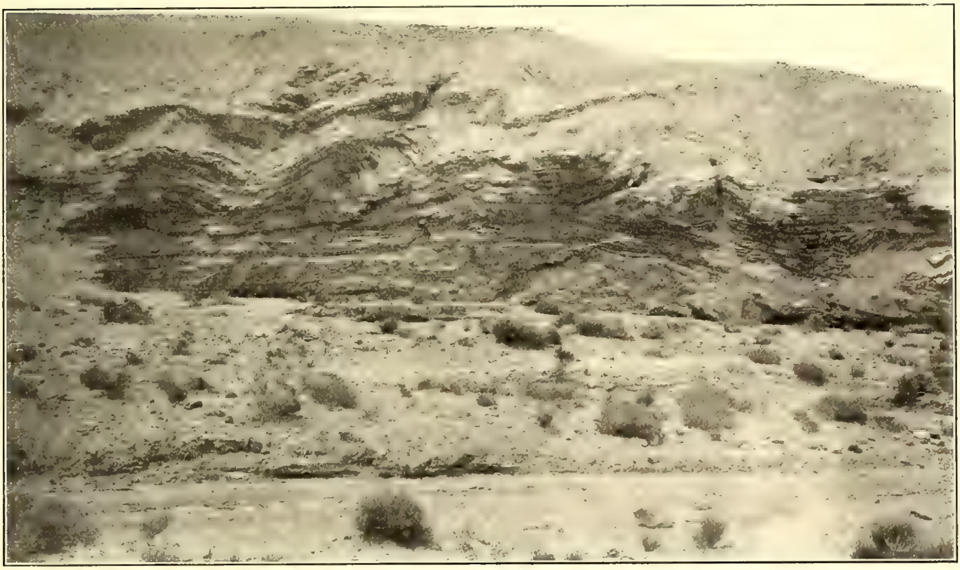
[13] Notes on the geology of eastern California, Am. Geol., vol. 17, pp. 67 and 68, 1896.

[14] The Eocene of North America, Journ. of Geol., vol. 8, pp. 455 and 456, 1900.

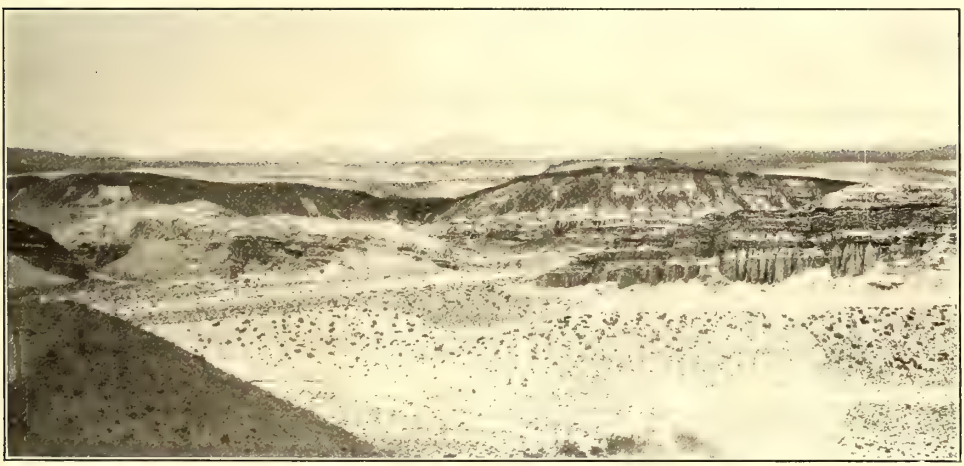
them to the Eocene period. Although the Black Mountain locality where Fairbanks collected leaves which were determined to be of Eocene age by Knowlton was not visited in the present reconnaissance, mammalian fossils of upper Miocene age, as determined by Merriam, were collected in the bluffs just west of Ricardo postoffice.

At the mouth of the cañon very light brown, rather fine breccia beds, showing imperfect bedding and cross-bedding, dip in a northerly direction. They are overlain by a thin bed of massive purple breccia which seems to be faulted against a lava by a strike-fault. The lava continues for about a mile up the cañon, which has cut a deep and narrow gorge through it, and then gives way to sediments which overlie unconformably the lava. Two miles to the east the basal beds of the sediments rest on granite. The basal sediments are predominantly dark red breccia, with thinner interstratified layers of light gray color, the whole aggregating approximately 250 feet in thickness. Next in the upward succession comes a light pink volcanic breccia forming one massive bed 100 feet in thickness, and cut by two strike-faults of fifteen and fifty feet displacement. This is succeeded by 150–250 feet of beds mainly gray in color, but with thin interspersed layers of dark red. Then come 300 feet of light gray, rather fine, poorly stratified breccias, capped by a flow of vesicular basalt about fifty feet thick. The outcrop of this flow is repeated by a normal strike-fault, and its upper surface has been eroded, as is shown by its rough floor, its variations in thickness, and by particles of the basalt in the overlying beds. The beds just under the basalt have been baked to a red color. The basalt forms a narrows in Red Rock Cañon just below the Ricardo postoffice. The beds below the basalt weather into badland forms reminiscent of Gothic architecture, examples of which are shown in plate 40B.

Above the basalt the material is for a few feet fairly well assorted and stratified and has probably been deposited by water. This is succeeded by light bluish-gray tuff and breccia interstratified with light yellowish-brown beds of the same composition and texture, the whole containing much fine gravel, and having an unknown thickness. The beds are more massive in character



A. Showing crumpling of less competent strata under compression where more competent beds have fractured or else not yielded to deformation, causing lateral movement along bedding planes. Borate member of Rosamond Series near Borate, Calico Mountains.



B. Characteristic erosion of Rosamond Series in Red Rock Cañon. The second escarpment is capped by a basalt flow. On the distant horizon are the peaks of the Sierras, with their debris slopes in the middle distance.

than they are persistently bedded; their degree of induration varies locally; and they merge northward into the alluvial debris of the Sierra Nevada slopes, from which they can scarcely be distinguished in color, composition, and texture. Bones of merycodonts, horses, and camels were picked up along the foot of the bluffs one-eighth to one-quarter mile west and northwest of Ricardo postoffice.

AGE OF THE ROSAMOND SERIES

Organic remains have been found in all the members of the Rosamond Series except the basal breccia. They were found in each of the five localities examined. But in only the Barstow syncline and Red Rock Cañon were determinable fossils obtained which serve to indicate the age of the containing beds. The bones discovered in these two localities belong, according to Professor J. C. Merriam, to mammals of the upper Miocene period.

ORIGIN AND MODE OF DEPOSITION OF THE ROSAMOND SERIES

The presence of fossil remains of characteristic fresh-water gasteropods and of abundant cursorial and plains-living mammals indicate that the strata of the Rosamond Series containing these fossils are of terrestrial fresh-water and subaerial origin. The fossil bones are checked and cracked as if they had been exposed for a considerable time to the action of the sun, frost, and abrupt changes of temperature, on the surfaces of an open plains country. Nowhere was a complete skeleton of a mammal found in place. Often remains of three or more different animals are mingled in the same deposit of fine material; for example, bones of horses, camels, dogs, and merycodonts. Horses are the most common fossils, but camel and deer bones were also quite abundant. Occasionally all or nearly all the bones of a limb would be found together in their proper anatomical position. Bones were also found in the breccia and conglomerate layers where those of different species were apt to be mixed together and to exhibit traces of wear.

The constituents of the Rosamond Series have been derived from two different sources: the one necessarily near the site of deposition, and the other perhaps a considerable distance away.

The greater part of the sediments—the granitic and volcanic breccias—had their origin in nearby areas tributary to the place of deposition. These areas must have possessed considerable elevation, in order to produce the great bulk of sediments. The lack of mature chemical weathering, shown by the arkosic material, and of any considerable mechanical attrition, because the boulders or smaller fragments are angular or subangular in outline, implies rapidity of erosion and deposition. For the above reasons it is thought that the coarser part of the series was derived from recently uplifted areas of considerable elevation. This seems to require an epoch of mountain-making sometime between the middle of the Miocene and the beginning of the Pliocene periods.

There is a very conspicuous and almost total absence of the decomposed products of mature weathering. It is probable that even the finer clays and mudstones of the Borate and of the fine ashy and shaly tuff members are mainly composed of fine volcanic ash. The absence of products of rock decomposition goes far towards proving that the Rosamond was deposited in an arid climate similar to that of the Mohave Desert today. But this analogy should not be pushed too far, for the interbedded layers of colemanite, gypsum, and limestone were most probably deposited on the evaporation of a body of water of considerable depth, since the colemanite layer is from five to thirty feet in thickness, layers of pure gypsum several inches thick are found, as well as more considerable thicknesses of what is probably chemically deposited limestone. An alternative hypothesis, that these minerals had their immediate origin in hot springs and solfataras opening directly into shallow lakes, perhaps only of seasonal duration, or in playas, has much to commend it, especially when considered in connection with the numerous evidences of shallow water deposition. These evidences comprise ripple marks, sun cracks, and rain prints, which are found on the finer as well as the coarser beds, and the layers of finer breccia and conglomerates interbedded with the fine shales and tuffs. Shallow lakes or ponds probably existed at times during the deposition of the fossiliferous tuff member, for they seem to be necessary to account for the presence of the gasteropods. The paucity or

absence of fossils in the Borate and the fine ashy and shaly tuff members (but one specimen of a *Planorbis* was found in these beds), as well as the presence of the colemanite, limestone, and gypsum layers, apparently indicates the salinity of the waters.

There was great volcanic activity before and during the deposition of the Rosamond. The larger fragments of lava were most probably derived from flows subject to erosion somewhere in the area tributary to the basin of deposition. Interbedded flows of both acidic and basic lavas make up a part of the Rosamond. But the fine volcanic ash was probably blown in by the wind or settled during explosive volcanic outbursts and need not have come from the immediate vicinity. The common view of the origin of calcium borate from solfataras and hot springs associated with the abundant contemporaneous vulcanism is likely to prove to be the correct explanation for the borax beds in this region.

The sediments of the Rosamond Series were probably laid down mainly as piedmont alluvial debris and as playa deposits, under the same conditions of desert aggradation as operate in the region at the present day, the deposits of the upper Miocene and present periods being indistinguishable in structure, texture, and composition. There were probably times when the climate became humid enough to form at least shallow lakes or ponds of sufficient freshness to permit the existence of gasteropods. Colemanite, gypsum, and limestone were deposited either by hot springs or solfataras in saline lakes, which might have been of shallow depth, or, having been leached from the surrounding rocks, were precipitated during a time or times of evaporation of a former fresh-water lake of considerable depth. Contemporaneous volcanoes added breccias and lava flows, as well as fine ash and coarser pyroclastic materials to the mass of Rosamond sediments.

The alternative hypothesis is that the Rosamond was deposited for the most part under climatic conditions of relative humidity, but so rapidly and with the source of the sediments so near that there was not time enough for chemical decomposition to take place and the materials were moved such a short distance that the amount of mechanical wear was negligible.

But even under these conditions it would be difficult to account for the practically total absence of decomposed material, especially in the finer members and towards the top of the series; and one would naturally expect to find a greater proportion of water-worn fragments than are actually present. Furthermore, it seems difficult to account for the interbedded chemical sediments without at least some times of aridity, although these may possibly have been merely accidents in a climate predominantly humid.

The realization that of necessity essentially local conditions of deposition must have prevailed has prevented the giving of formation names to the different divisions of the series and the consequent attempting of the correlation of beds of like characteristics in the different localities examined. It is, however, realized that the series as a whole is a fairly homogeneous unit and that the same general origin and conditions of deposition can be invoked to account for the characteristics of the strata in all of the different localities.

FIRST EPOCH OF DEFORMATION OF THE ROSAMOND SERIES

The Rosamond Series has suffered the effects of two epochs of deformation. The structure produced by the first diastrophism has been described in the descriptions of the various localities. It is noteworthy that the deformation produced not only folding but also faulting both of the reversed and normal types. The folding was both of the broad and open variety and of the intensely compressed form, accompanied by overthrusting. The massive, more competent beds appear to have deformed into the broad, gentle folds, or to have been in places only tilted; and the faulting in these beds is in many places certainly of the normal type. As many of the fault planes are vertical or very nearly vertical, some of the faulting may have been produced by upthrusting. The finer bedded, less competent strata in the Calico Mountains exhibit typical Appalachian structure with close folding and overthrusting. It is quite probable that, at the time of the earlier deformation, the Rosamond beds formed the surface rocks of the region deformed, and that the deformation occurred soon after the deposition of the beds.

THE FIRST CYCLE OF POST-MIOCENE EROSION

The deformed Rosamond has everywhere been extensively eroded. In the areas where the old erosion surface has been preserved by later lava flows and alluvial cappings it is seen to be one of virtual peneplanation (pls. 35B and 37B). In the locality north of Barstow, in the Calico Hills, and at Black Mountain, the tilted, folded, and faulted beds of the Rosamond have been beveled to an essentially even surface. A very notable and peculiar feature is the almost total absence of the effects of mature weathering in the superficial layer of the old erosion surface.

That portion of the western Mohave Desert situated south of a line connecting the towns of Mojave and Barstow and west of the Mojave River is a gently rolling or nearly flat country. All of the hills in this western part of the desert, with the exception of the range extending west from Rogers dry lake to northwest of Rosamond, are low-lying residuals. East and north of Mojave River the ranges are more numerous, more rugged, and higher. In this portion of the desert there is a greater amount of later lava flows, while in the southwestern part there has not yet been found any evidence of this later vulcanism, and it is probable that none—or but very little at the most—will be found. The present differences in altitude and relief of the two portions, therefore, is probably accounted for by the lava flows in the northern area and by their subsequent deformation. The country to the north and east has perhaps been more recently uplifted and has not yet reached the advanced stage of erosion possessed by the country to the west, where the former cycle of erosion still reigns in the main.

Hershey has expressed the belief that the detrital filling of the western portion of the Mojave Desert is a relatively thin veneer over the old bedrock surface, and the data collected recently support this belief. His remarks are quoted in full:

> The only extensive portion of Southern California, so far as seen by the writer, apparently remaining nearly in its late Pliocene condition is the Mohave Desert. Professor N. S. Shaler* says of it: "The most

* Broad Valleys of the Cordilleras, Bull. Geol. Soc. Am., vol. 12, p. 290.

complete effacement of the original valleys appears to have taken place in the region known as the Mohave Desert. Here the detrital slopes have risen to near the tops of the ranges.'' I entered the region with that idea in mind and came out convinced that it requires a radical modification. There are, indeed, thick accumulations of detrital material that have been built up close to the foot of such prominent ranges as the Tehachapi and the Sierra Madre, and may have buried the foothills, but in the central and by far the larger portion of the desert region I do not believe the detrital slopes have filled the broad basin-like valleys to a depth greater on the average than several hundred feet. Low knobs of granite occur at many places near the center of these basins, and where cañons have been cut into the detrital material, as by Mohave River, hard rock has been encountered at many points at no great depth. There is an area thirty miles long by three to four miles wide, and another thirty miles long by twelve to fifteen miles wide, of undulating granite comparatively free of detritus and characterized by long, broad, low, smooth ridges in which the granite (much weathered and softened) is rarely more than ten feet beneath the surface, and is often uncovered by railway cuts at three to five feet. These ridges are surmounted by knolls of broken pegmatite, and in places rise into short, rugged hill ranges, but rarely reach the dignity of mountains.

So strong was the impression that I was traveling over a country that had been reduced nearly to a uniform level by erosion, that it seemed natural to refer to it in my field notes as the granite platform. I should hardly like to call it a peneplain, as evidences of actual and completed base-leveling, if they ever existed, are now obscurred by the more recent detrital slopes and alluvial deposits that floor the broad basins. It is a land whose topographic forms have reached the stage of old age but not that of senility. On the granite areas denudation effaced most of the rugged mountains and left only a few standing widely separated from each other. On a peneplain these would be classed as monadnocks. Where the rocks were more resistant, as on the gneiss, schist, quartzite, and limestones east of the main granite area, residuals were more numerous, and that region now has many rugged ranges.[15]

In the center of the basin between Black Mountain and the outcrop of the Rosamond Series in the locality north of Barstow strata resembling lithologically those of the Rosamond outcropped in the bank of a shallow arroyo. Low knobs of granitic rock and lava outcrop in the basins on all sides of the Barstow syncline. The Mojave River in the vicinity of Barstow is at present in the process of uncovering residual knobs of lava once buried beneath coarse alluvium. This river is excavating a narrows at the town of Victorville through a residual knob of granite, although it flows through an alluvium-covered area of

[15] The Quaternary of Southern California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, pp. 4 and 5, 1902.

very low relief north and south of that town. The present surface of the granite north of the Barstow syncline is an even surface of soft, rounded slopes of very little relief (pl. 35B); and the same characteristic is exhibited by the granitic areas south of Kramer and between Rogers dry lake and the base of the Rosamond Series north of Rosamond station.

This old surface can be traced on the crests of the Sierra Nevada and Tehachapi mountains in the vicinity of Tehachapi Pass and on the summits of the latter range northeast of Tejon Pass.

On a trip to the summit of the San Bernardino Mountains, over that portion of the range mapped on the western half of the San Gorgonio Atlas Sheet, the features of two, and perhaps even three, different cycles of erosion were noted. If there have really been three different cycles there, the middle one should be regarded as only a partial cycle or a sub-cycle, for it was brought to a close in the stage of late maturity or early old age. The summit of the San Bernardino Range is for the six miles of its length, from San Gorgonio to San Bernardino mountains, a long, rather even-crested ridge, which is represented in plate 41A. Whether the evenness of this crest is to be attributed to peneplanation, to the uncovering of the uniform upper surface of a batholith or of an old erosion surface which has been formed by streams, is a moot question. The rocks in this ridge do not seem to differ in composition or in erosion-resisting qualities from the other rocks of the range. Accordance of summit levels is not a particularly marked feature of the San Bernardino Range, although there is a tendency for peaks along the east-west divides, which are the prominent water partings in this portion of the range, to exhibit a sort of accordance which gives the highest summits along a line which runs approximately north and south from the range's highest summit, San Gorgonio Mountain.

A broad valley, partly filled by a lake, will be noted in the middle ground of plate 41A. A view of the marshy floor of this same valley three miles nearer its source, with the low rounded mountains in the vicinity, is given in plate 41B. This is the valley of Bear Creek, which contains three lakes probably owing

their basins mainly to the solution of the metamorphosed limestone in which they are situated. The western and largest, Bear Lake, has been greatly enlarged by the construction of a dam at the head of Bear Creek Cañon until it is now five miles long and, at the maximum, a mile broad. The dam is now being heightened so as to increase considerably the area of the lake. Other broad valley flats near the heads of streams and upland areas between the streams are: Horsethief, Cactus, Monarch, Burnt, Union, Little Pine, Big Pine, Arrastre, and Broom flats; Holcomb, Little Bear, and Grass valleys; and other flat areas to which no particular names are applied. Not all of these are in limestone areas, although it is not known how many may possibly owe their origin to solution of calcareous rocks. The important point, however, is that the upper courses of these streams were developed and are still in an older cycle of erosion than their rejuvenated lower courses, and that many, at least, of these broad open valleys cannot be accounted for by solution of limestone. There is, for instance, the broad flat known as Big Meadows, near the head of Santa Ana River, which merges into a terrace which has a height four miles farther down the river of nearly four hundred feet above the present river bed. Few changes in topography can be more startling than will be noted by one who, after climbing the steep slopes of a cañon in the northern foothills of the San Bernardino Range—as, for instance, any one of a half dozen cañons in the area mapped on the northwestern portion of the San Gorgonio Atlas Sheet—suddenly comes upon a broad divide and finds broad valleys of low gradient, separated by low rounded hills, leading down in the opposite direction. Or he may look at the difference in the character of the topography on the opposite sides of the divide separating the drainage tributary to the Pacific Ocean from that sloping towards the Mohave Desert, in the area mapped on the northern portions of the San Bernardino and Redlands Atlas sheets. The southern side of this divide is characterized by its extreme youth and by its deep cañons which reach back to the very head of the divide; the country and streams have much less relief to the north of the divide, where the topography bears a much maturer aspect. Doubtless much of this difference in

A. Level-topped crest of summit ridge of San Bernardino Range from north side of Bear Valley, looking south. Bear Lake and broad valley of second sub-cycle in middle distance.

B. Broad marshy valley and low rounded hills developed in the second sub-cycle near head of Bear Creek, San Bernardino Range.

relief is directly due to the circumstance that the southwardly flowing streams have been much aided in their work by recent faulting along the south flank of the range, which has uplifted that flank relative to the region to the south, but this faulting belongs to the recent uplift which began the present cycle of erosion. Recent stream-cutting has exposed twenty feet, with lower limit unknown, of well decomposed black loam, free from pebbles, boulders, and other arkosic material, in upper Holcomb Valley, near the head of Van Dusen Cañon. It is said that the bedrock was never reached by the extensive placer mining in the broad marshy meadow of this valley and that consequently it must lie at a considerable depth. Some of these wide flats at the heads of water courses, such as Holcomb Valley, Cactus and Broom flats, and the unnamed region about Mound Springs, constitute the divides for streams flowing in opposite directions.

Although the hills surrounding Holcomb and Bear valleys have well-rounded, fairly gentle slopes and rounded exfoliated knobs of granitic rocks, there is approximately a relief of two thousand feet between their summits and the valley flats. The high terrace near the head of Santa Ana River contains a large amount of coarse boulders and gravels which are certainly not the products of anything like an extreme old-age stage of erosion. Even accounting for a considerable portion of the present relief by tilting, warping, and possible faulting, it is yet evident that the surface of the older sub-cycle had several thousand feet relief between the Big Meadows of the Santa Ana and the surrounding mountain summits. The stage of erosion reached in the San Bernardino Range at the end of the sub-cycle was that of late maturity or early old age. A picture of this range at the end of this sub-cycle would probably duplicate in large measure the present aspect of the Wichita Mountains of Oklahoma, rising, as the latter mountains do, abruptly from a nearly flat plain and penetrated by rather broad, open valleys.

There is a disposition to correlate the surface developed during the first cycle of post-Miocene erosion with the surface of the summit ridge of the San Bernardino Mountains. The sub-cycle does not seem to have advanced to the stage one would expect if it is the same as the more advanced stage in the Mohave

Desert. The shore line of the late Pliocene and early Quaternary Pacific Ocean is yet unknown east of the 118th Meridian, while it is known to have reached nearly to the Mohave Desert, near the head of the Santa Clara Valley. It is possible that the upper courses of the drainage of the sub-cycle, which are also the present courses, were farther from the ocean than the streams in the western portion of the present Mohave Desert, granting, of course, that the climate of that cycle was humid enough, or that the present mountain barrier was so broken down, that the base-level of that region was the surface of the Pacific Ocean. This can be by no means proved when one considers the scantiness of the evidence for or against the normal cycle as opposed to the arid cycle, although one is strongly disposed to incline toward the cause of the normal cycle. For it appears probable that a normal cycle could have reached an advanced stage sooner than an arid one and the time available seems short for the work of either cycle. If the correlation suggested above is accepted, the second or sub-cycle might be regarded as having been in operation during a resting spell in the epoch of diastrophism to which the San Bernardino Range owes its present altitude and indirectly its present form. But the questions are still open: whether (1) the first cycle of erosion in the Mohave Desert had advanced to a stage in which it may fitly be called a peneplain; (2) whether that cycle was an arid or a normal humid one; (3) whether the summit ridge of the San Bernardino Range owes its markedly level crest to erosion in the post-Miocene or in some earlier cycle, or to some other cause; and (4) where to place the San Bernardino sub-cycle with reference to the first cycle of post-Miocene erosion in the Mohave Desert.

VOLCANIC ACTIVITY NEAR THE END OF THE FIRST CYCLE OF POST-MIOCENE EROSION

The folded and faulted Rosamond Series, with its surface subsequently beveled during the first cycle of post-Miocene erosion, is covered by an olivine basalt flow on Black Mountain and to the north (pl. 42A and fig. 2). At the extreme western end of the exposure of the fossiliferous tuff member in the locality north of Barstow is a basalt-covered butte the precise

relationship of which with the fossiliferous beds could not be ascertained, owing to the contact between the two being everywhere covered by wind-blown sand. It is thought that this basalt was originally a part of the flow covering Black Mountain, for basalt outcrops at several places in the basin between the two localities. Similar relations are found between the Rosamond and later lava in the Calico Mountains where, according to Lindgren's field determination, a hornblende andesite forms the highest peaks of that range. From a distance it appeared that the Rosamond in the range south of the Mohave River Valley, southeast of Daggett, was also overlain by lava. Lava also overlies the tilted and beveled Rosamond in the flat-topped buttes just northwest of Daggett. Olivine basalt was found on a low ridge north of the Mohave River between Barstow and Daggett, but its relation to the underlying beds was not determined. As has been said before, this later lava, for the most part at least, is absent from the southwestern corner of the Mohave Desert.

DEFORMATION FOLLOWING EPOCH OF VOLCANIC ACTIVITY AND BEGINNING A NEW CYCLE OF POST-MIOCENE EROSION

The basalt capping Black Mountain has been folded, with possibly some minor faulting, by orogenic movement since its outflow (fig. 2). The folding is beautifully shown from north to south along the course of Black Cañon. At the north, near the head of the cañon, the greatest dip of the basalt surface is $1\frac{1}{2}°$ to the northwest, which may be the angle of original deposition. Southward the surface is arched very gently, with possibly one or more minor step faults, as far as the summit of the mountain. From the summit southwards the basalt plunges steeply downwards, so abruptly indeed that from a distance the mountain in profile looks very much like a "block-faulted" one, with the fault-scarp on the southern side. Although it is possible that some minor faulting occurred on the south side, it seems none the less certain that Black Mountain owes its present form mainly to folding.

The basalt northeast of the head of Black Cañon has been

tilted and presumably faulted. More or less isolated blocks of it, forming mesas or low-lying outcrops, lie at various levels, surrounded by alluvium, in the basin northeast of Black Mountain and between that mountain and the exposure of the Rosamond Series north of Barstow.

The Rosamond in the Barstow syncline has been gently unwarped, presumably without faulting, during this second diastrophic epoch.

The hornblende andesite capping the Calico Mountains and unconformably overlying the beveled surface of the folded Rosamond Series has been faulted against the Rosamond along a nearly perpendicular fault plane. The fault may have been caused by upthrusting. It was noted by Lindgren and Storms.

The present Sierra Nevada, Tehachapi, San Gabriel, and San Bernardino mountains probably owe much the greater part of their altitude to this second epoch of post-Miocene deformation; and the eastern Mohave Desert almost certainly received its present orographic features from this diastrophism. The general lines of structure may, however, very likely have come into being as the result of a previous deformation. The great thickness of coarse materials in the Rosamond apparently indicates the presence of mountains at the time of its deposition, as does likewise the thick coarse deposits of the Fernando on the coastward flanks of the southern Coast Ranges and the San Gabriel Mountains. But the bulk of the Fernando is probably younger in age than the Rosamond, and would seem to have been deposited during the period roughly corresponding with the first cycle of post-Miocene erosion in the Mohave Desert. If the drainage of that cycle had an outlet to the ocean the sediment derived from the degradation of the desert ought to have the quality of being recognized by its lithologic characteristics.

The later movement which has effected the ranges bounding the western Mohave Desert can be recognized directly in their present high altitude above the surrounding country and by their bounding fault-scarps; and indirectly by the rejuvenation of streams and other erosive agencies. The bounding ranges are not in topographic adjustment with the Mohave Desert. The direct cause of this lack of topographic adjustment was the deformation, while its indirect result was the rejuvenation.

Fault-Scarps.—The San Bernardino Range is bounded on the south by a fault-scarp, along the base of which runs the San Andreas rift.[16] There is probably a fault-scarp along the north base also. The scarps, which are considerably eroded, are about equally steep; the amount of upward movement on both the faults has probably averaged about four thousand feet. The San Gabriel Range, the Sierra Pelon, and Liebre and Sawmill mountains, forming the southwest border of the Mohave Desert, have a fault-scarp on their north bases. The southern front of the Sierra Nevada east of Tehachapi Pass shows much topographic evidence of a recent fault-scarp. The base of the range forms a straight line for miles; triangular facets are evident between the short, deep, narrow cañons cutting back into the mountain front; the cañons are not topographically adjusted to the basin south of the mountain front; and features which are apparently caused by a physiographic rift between the bedrock slope of the mountains and the debris apron were noted. The scarp was last seen a mile or two west of Red Rock Cañon, the region farther east not being examined.

Rejuvenation.—Active cañon-cutting is in process along the fault-scarps. The lower courses of the broad alluviated valleys in the San Bernardino Mountains have become deep narrow cañons. Cottonwood Creek, which emerges from the south base of the Tehachapi Mountains about twenty-five miles east of Tejon Pass, has cut a series of three alluvial terraces, although not all of this cutting may have been caused by recent uplift. The citing of many other examples would only be unnecessary repetition. There is a patch of cemented gravel on the east wall of Furnace Cañon, and fifty feet above the present cañon bed, near where that cañon leaves the north base of the San Bernardino Range. Another gravel remnant was noted much higher above the stream bed and higher up in the range on the dividing ridge between Wild Rose and Furnace cañons. Well-cemented stream gravels containing placer gold and proboscidean bones

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[16] Mendenhall, W. C., The hydrology of San Bernardino valley, California, U. S. Geol. Surv., W. S. and I, paper no. 142, pp. 30 and 31, 1905.
Fairbanks, H. W., Report of the State Earthquake Investigation Committee upon the California Earthquake of April 18, 1906, Carn. Inst. Publ., no. 87, vol. 1, pt. I, pp. 43–47, 1908.

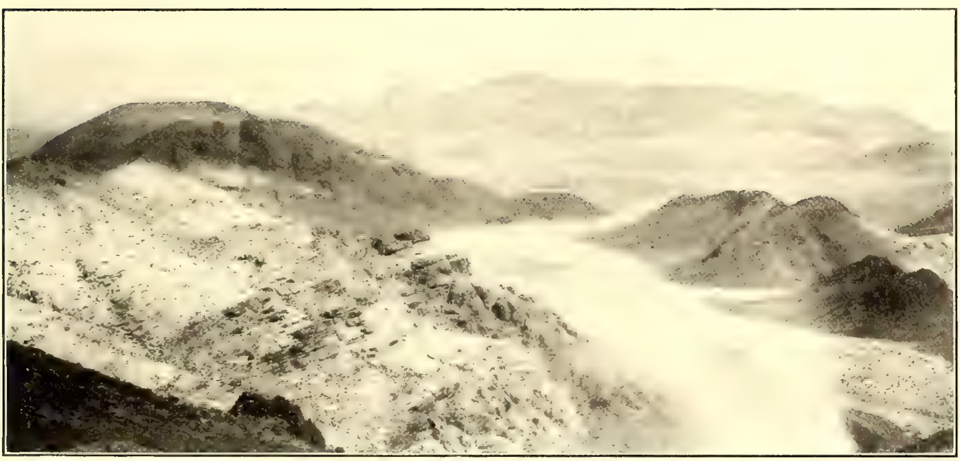
are found along the streams tributary to Red Rock Cañon, and unconsolidated water-rounded gravels and boulders are present in the larger valleys, where they mantle the ridge facets at the lower ends of divides between the lesser tributaries.

Wide, high-level valleys with their broad bottoms well filled with debris are found in the upland area north of the Mohave River between Barstow and Daggett, in the Calico Mountains north of Borate (pl. 42B), and in the hills south of Mohave River from Daggett to the eastward. These valleys were filled after the latest extrusion of lava, the flows of which they have dissected. Their lower courses are rejuvenated by steep V-shaped cañons tributary to Mohave River in the sense that the lowland area into which they open is drained by that river. A well defined alluvial terrace can be traced in the valley of Mohave River from east of Daggett to south of Victorville, with its lower and upper limits unknown.

The dissection of the slopes of the later alluvium and of the bedrock of the Rosamond Series in the locality of the Barstow syncline has probably been caused by a slight upwarp of the peneplained surface during the last period of uplift. The surface slope of the surface alluvium and the bedrock surface under it averages 2°, which is the average angle of slope of the debris aprons being formed at present; where an indurated layer occurs its angle of dip is the same as that of the surface slope (pl. 36B), and the slope of the granite north of the outcrop of the Rosamond Series is also graded and in conformity with that of the dissected alluvium (pl. 35B).

Probable Antecedence of Black Cañon.—There is considerable evidence that Black Cañon may be antecedent in that part of its course which cuts through the Black Mountain uplift. After leaving the vicinity of the American Opal Company's prospect the valley has a general southwesterly direction and a shallow V-shaped cañon with walls terraced on both sides by resistant basalt. Then changing its course abruptly to the south it cuts through Black Mountain near its western end. By taking a course less than a mile to the westward it would have escaped cutting through the resistant lava cap, and the latter course, in addition to being through much less resistant beds, would have

A. Olivine basalt flow covering peneplaned surface of tuff-breccia member of Rosamond Series near the head of Black Cañon. The basalt has probably been faulted in forming the peaks on the horizon line.



B. Looking south towards the mining camp of Borate, Calico Mountains. Tuff-breccia member of Rosamond Series in foreground, capped in right middle distance by later lava flows. The low lying light colored beds in the distance belong to the Borate member, and the hills above them are composed of lava. In the middle is a typical high-level valley.

approached more nearly a position consequent to the slope produced by the latest deformation. So the stream can not be consequent to this deformation. The fact that the basalt flow formed the land surface at the time of the uplift precludes the origin of Black Cañon by superimposition.

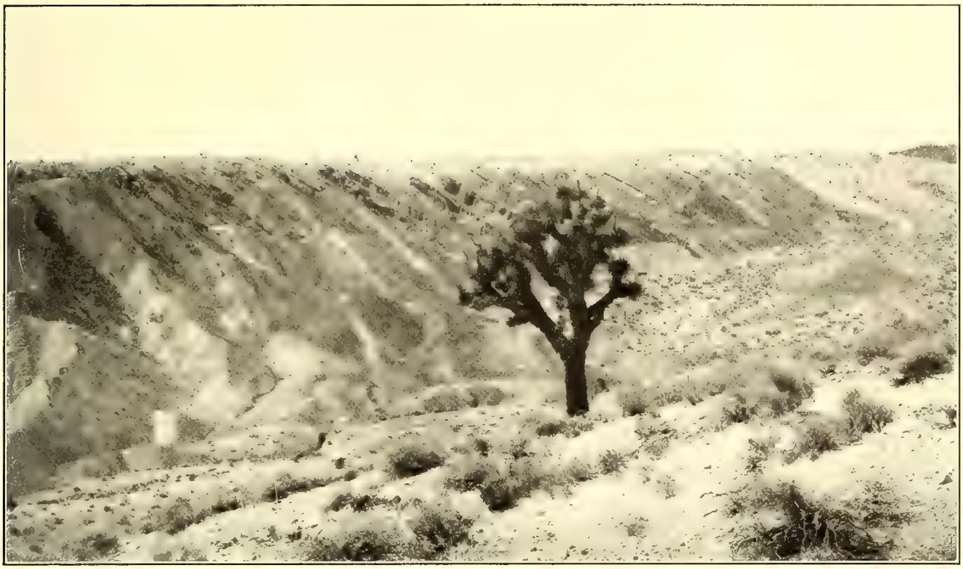
The lava at the north end of the cañon is apparently undisturbed, or at most disturbed but little, from its original angle of deposition, and this suggests that the valley was once for its entire length through the nearly horizontal lava, which has since been domed up to the south to form Black Mountain, the valley maintaining its course by down-cutting during the doming. The portion of the cañon through the mountain is deeper, narrower, and physiographically younger than the upper portion. There is no stream in Black Cañon except during periods of rainfall; and this fact has its significance in the consideration of the slowness of the last uplift and the comparative rapidity of erosion accomplished in very infrequent periods of torrential rainfall, provided the cutting was accomplished during climatic conditions the same as those of the present day. Black Mountain has the only valley of any considerable size in the Black Mountain region, and it is the only valley whose gradient is in anything like reasonable adjustment with the adjoining basin. Other valleys in its neighborhood have scarcely passed beyond the stage of gullies.

ALLUVIAL SLOPES AND PLAYAS

Composition, Texture, and Structure.—The most important and general geologic process of recent date on the Mohave Desert is the denudation of the higher mountain slopes and the complementary alluviation of the lower slopes and the basin areas between the ranges. Reasons have already been given for the opinion that the mantle of alluvium in the desert basins is not of great thickness. The thickest deposits of later alluvium lie on the lower slopes of the debris aprons. This latter alluvium resembles in composition, texture, and structure the coarser strata of the Rosamond Series, from which, indeed, it is often distinguished with difficulty. There is a conspicuous lack of water-rounded and polished pebbles and boulders in the larger part

of the alluvium, where the rounded surfaces are not polished and are rough and pitted, and probably owe their form to exfoliation. The boulders strewing the surfaces of the fans have "shelled off" under the action of sudden heating and cooling. True water-worn pebbles and boulders *that have preserved the effects of polishing* are found in the desert only in the beds and walls of the cañons and arroyos and the valley of Mohave River. The finer materials of these debris slopes are almost wholly arkosic, being rough, angular particles of quartz, feldspar, the ferro-magnesian minerals, lava, metamorphic and crystalline rocks, and the more indurated sedimentary rocks. Some boulders of the agglomeratic materials of the more resistant portions of the Rosamond Series are found near the outcrops of that series, in which places doubtless much of the arkosic material of the later alluvium is only the redeposited or disintegrated arkoses of the Rosamond. In many places much wind-blown sand is mixed with the alluvial debris, derived from the low sand dunes which are a conspicuous feature of the desert basins and lower mountain flanks. Close to the steeper bedrock slopes of the mountains the debris is merely a pile of unassorted material of heterogeneous texture, but on the middle and lower slopes of the fans, as seen in the sections cut in them by the arroyos, there is generally some assortment into poorly defined layers of more homogeneous texture. The alluvium is locally indurated. The mean surface angles of the alluvial debris aprons average about 2°, being of course greater at their junction with the bedrock of the mountains and gradually dying out to horizontality as a nearer and nearer approach is made to the basin playas.

The material of the playas is quite fine clay and chemical deposits, mixed with some wind-blown sand, which has lodged there during the very intermittent periods of their submergence. There are also rather fine pebbles of resistant rocks stained dark brown on the surface with iron and well polished, partly by water action and partly by attrition of grains of wind-blown sand. Clay concretions of grotesque shapes are also found. The smooth, hard, wind-swept surfaces of the playas exhibit sun cracks, rain prints, trails of plants and animals, and ripple-marks after periods of precipitation and inundation and before



A. Northwardly-dipping strata of the resistant breccia member of the Rosamond Series in the south limb of the Barstow syncline have been beveled by peneplanation and capped with a mantle of later alluvium. The surface of the alluvium slopes toward the local basin at an angle of 2°. Recent stream dissection in middle distance.

B. Recent dissection of piedmont alluvial slopes. The flat-topped divide in the center, composed of the later alluvium, slopes towards the local basin with a surface angle of 1½°, yet the cañons have been excavated since the deposition of the alluvium.

wind action has removed or covered their traces. These surfaces are sparsely strewn with hard, polished pebbles. The action of the wind, which carries away the finer particles of clay, sand, and chemical deposits, is not able to remove the larger pebbles which tend to accumulate on the surface because of the removal of the finer materials.

Origin of Materials and Processes of Formation.—The processes of alluviation can be seen in constant operation throughout the desert. In the neighborhood of the bedrock slopes of the mountains ordinary talus slopes are forming of disintegrated rocks which lie in a heterogeneous dump at the foot of the slopes where they have fallen and rolled under the force of gravity. Farther out from the bedrock slopes the material has been deposited with rude stratification by sheet and slope wash, and down the gullies and cañons by streams existing only during times of rainfall, which in this region often attains the dignity of torrential cloudbursts. The boulders and pebbles brought down the cañons, arroyos, and gullies have their edges more or less rounded by attrition with their neighbors and the bedrock. Those which have been brought down by sheet or slope wash or have rolled or fallen into their present position preserve almost all of their original angular form and rough edges. All of the coarser fragments "shell off" upon exposure, the thin shells disaggregating to form the finer matrices, while the still finer particles are swept away by the wind. The wind, which by its selective action in removing the finer material in which the larger fragments would ultimately become wholly or in part imbedded, tends to keep the latter as projecting boulders and pebbles strewn over the surfaces of the slopes and therefore longer exposed to the disintegrating action. Only the finest particles are carried by water and wind to the playas in the midst of the basins where the soluble materials derived from the encircling rocks is deposited upon the evaporation of the thin sheets of water occasionally submerging the playas. The natural baking of the playa surfaces by the heat of the sun and the cementing of the sediments by aid of the water and chemical precipitates serves to protect a portion of the fine sediments and chemical precipitates from the erosive force of the wind.

The remainder is carried away by the wind to the adjacent slopes from which a portion again returns to the playas during the succeeding rainy seasons. It is a moot question whether in many cases the playas are increasing their thickness of sediment or even holding their own, for sedimentation upon them is very slow and the wind is almost perpetual in its action and is always provided with tools of sand. The wind-blown sand is mainly deposited in dunes and hillocks on the stoss sides (here the western and northwestern slopes) of debris aprons, mountain slopes, and larger valleys. Occasionally under the impetus of a strong wind the sand blows into rippled drifts like dry snow in a prairie blizzard.

DISSECTION AND CAÑON-CUTTING IN ALLUVIAL SLOPES

For the trenching of some of the alluvial slopes of the Southwest an explanation is apparently required to account for the dissection of a graded surface by some process which involves neither the recent upwarp of the surface nor the change in differential altitude of the base-level. The hypothesis of recent climatic change has commonly been advocated to explain this dissection. It has been assumed that abundant evidence for this view is found in the drying up of the large Quaternary lakes of the Great Basin and in the diminution of glaciation. In the western Mohave Desert no evidences of Pleistocene lacustral conditions have yet been found. Neither are there any remains of Pleistocene organisms nor of maturely weathered soils. And so in the absence of supporting criteria it is desirable to test the value of the dissection of alluvial slopes as an indicator of recent climatic change.

The familiar process of the formation of alluvial terraces by the erosion of a formerly aggraded flood plain is a process which works in arid regions as well as in regions of greater rainfall. That such terraces are developed as well under conditions of local base-level as under direct control of sea-level is patent. The Great Basin, in common with other arid regions, is essentially a region of local base-levels, in which the same great principles of erosion and deposition hold as in other more

humid regions, although the relative importance of different processes of erosion vary. The general processes of alluvial fan formation on the boundaries between areas of topographic unconformity are also so well understood as to need no explanation at this time. But it is the precise application of the processes by which terraces and alluvial fans are formed to the particular problem in mind, namely, the dissection of alluvial debris slopes in arid and semi-arid—and for that matter, to a certain extent in more humid regions—that has not yet been clearly made. For this reason it is desirable to outline the processes and to trace their genetic influences upon the final product.

There is postulated in the beginning a region of topographic unconformity. In the beginning of the youthful stage of a cycle of erosion, this topographic unconformity can be produced either by faulting, by folding, by warping, or by tilting of a previously existing surface, neglecting, as not pertinent to the discussion, displacements along the littoral zone between sea and land. Topographic unconformity may also exist at the mature stage of an erosion cycle when a relatively resistant terrane is in juxtaposition with one not so resistant.

The first work of the agencies of gradation is to bring topographic unconformity into conformity. Degradation of the high areas is accompanied by the complementary aggradation of the adjoining lower lying areas, and this is accomplished regardless of base-level, local or regional. So alluvial fans are formed in the early stages of a normal cycle as well as of an arid cycle. The causes of deposition of fan material are checking of gradient, distribution of the stream over a larger surface, and evaporation and seepage of the water. The rock falling from the cliff lodges at its bottom, or rolling down an incline comes to rest when friction overcomes its momentum. The velocity of running water is lessened on an abrupt decrease of gradient, causing the deposition of much of the larger material carried in suspension. The deposition of debris successively carries the point of initial checking of the velocity farther and farther up the slope and would, if the process went on unchecked, finally mantle the slopes to their very heads. But the destruction of this ideal slope goes on apace by the agency of running water and subor-

dinately by the wind. The sheet and slope water, as well as that concentrated in more definite channels, having had its excess of load removed when its velocity was first checked, is able to erode farther down the slope. Thus it is that one stream, in the desert as well as in regions of abundant rainfall, may have many places along its course where contemporaneous degradation at the expense of former aggradation is taking place. Coupled with this process is the fact that the drainage area of the stream, up to the stage of maturity, is being constantly increased; while from maturity onward the drainage basin is being worn lower and lower, so that in the first part of the erosion cycle the amount of water available for erosion, climatic conditions being fixed, is constantly being increased, while in the second part of the cycle the amount of material for the water to transport, provided the area is not undergoing diastrophic changes, is constantly being diminished. This gives the underloaded water a chance to erode materials from surfaces where formerly the overloaded water was forced to deposit them. Hence much material strewn in earlier stages over surfaces contiguous to topographic unconformity will later be dissected and removed. The fact that, as long as the slopes remain steep, vertical downcutting will be much greater than lateral planation will account for the deep, narrow cañons excavated in the bedrock of the higher portion of an area exhibiting topographic unconformity.

The processes of terrace formation and the dissection of alluvial slopes which are salient features of the normal cycle of erosion in humid climates are none the less perfectly normal phenomena in regions subjected to the arid cycle. This appears so obvious that it should not be necessary to do more than to call attention to the process in order to have it generally accepted, yet there has been a notable tendency in recent years to explain recent dissection of alluvial slopes on the desert as caused by renewed uplift or change of climate. Occasionally such dissection has been taken as proof of recent renewed uplift or change of climate without taking the pains to prove such uplift or climatic change by other data bearing more directly on the problem. That renewed uplifts or recent climatic changes have taken place is indeed quite probable, but they cannot be

proven by recent dissection of alluvial slopes or cañon-cutting, unaccompanied by other more distinctive criteria. The difficulty of proving recent earth movements and climatic changes is conceded to be very great in many instances, but doubtful criteria should not be applied without at least conceding the possibility of other hypotheses to explain the criteria. Nor is it probable that more extended regional studies will aid in this particular matter. The normal dissection of alluvial slopes in the arid region is naturally progressing over the entire area subjected to the same conditions. Were it possible to find a region at grade for a given set of climatic conditions, subsequent rejuvenation, caused by climatic change solely, would probably operate at different points in the same drainage system simultaneously, for it does not seem reasonable to hold that any slope graded for a certain climate would be in a corresponding condition under a different climate. Theoretically at least dissection of slopes might be proved to be caused by change of climate near the end of a cycle of erosion. In earlier erosion stages it is probably difficult, if not impossible, to prove change of climate by cañon-cutting and dissection of alluvial slopes, unaided by other evidence.

Another by no means unimportant factor in this dissection is noted by Gilbert in his monograph on Lake Bonneville. He says:

> As in other desert regions, precipitation here results only from cyclonic disturbance, either broad or local, is extremely irregular, and is often violent. Sooner or later the ''cloud-burst'' visits every tract, and when it comes the local drainage-way discharges in a few hours more water than is yielded to it by the ordinary precipitation of many years. The deluge scours out a channel which is far too deep and broad for ordinary needs and which centuries may not suffice to efface. The abundance of these trenches, in various stages of obliteration, but all manifestly unsuited to the every-day conditions of the country, has naturally led many to believe that an age of excessive rainfall has but just ceased—an opinion not rarely advanced by travelers in other arid regions (p. 9).

For the above reasons it is concluded that no satisfactory evidence of recent climatic change has yet been secured in the western Mohave Desert, whatever may be the force of the analogy of the retreat of Pleistocene glaciation and of the dessication of the Pleistocene lakes of the Great Basin.

SUGGESTIONS AS TO CORRELATION

The later Cenozoic history of the western Mohave Desert apparently exhibits marked similarity with the sequence of events in the southern Coast Ranges during that time, as well as to the adjoining Great Basin region.

According to Ball,[17] the second Tertiary rhyolite is everywhere in southwestern Nevada and eastern California separated from the overlying Siebert lake beds by a marked erosional unconformity. The Siebert lake beds, originally described by Spurr from the Tonopah region,[18] are correlated by Ball with the Truckee sediments of the Pah-Ute Lake, referred to the Miocene by King,[19] and with the Esmeralda formation, described by Turner,[20] in the Silver Peak Range. In addition he finds beds which he refers to the Siebert in many localities throughout the southern Great Basin. In the Southern Klondike Hills and the Silver Peak Range rhyolites and silicious latites and dacites are interbedded with the Siebert lake beds without erosional unconformity. Ball believes the second rhyolite to be largely of early Miocene age, the andesite and dacite to be also of comparatively early Miocene age, the third rhyolite to cover the middle and late Miocene and early Pliocene, and the basalts to range in age from the Miocene to Pleistocene, the major extrusions occurring in late Pliocene and Pleistocene times. The Siebert lake beds are therefore, in Ball's opinion, early upper Miocene in age.

Ball summarizes the Cenozoic history of southwestern Nevada and eastern California as follows:

> The Eocene inaugurated the Tertiary period of volcanism and lake sedimentation processes, accompanied by important deformation, erosion, and ore deposition. The Tertiary igneous rocks, being largely in flows, in contradistinction to the intrusive post-Jurassic rocks, produced but little contact metamorphism. The permanency of the structural lines, initiated probably in early Cretaceous time, has already been mentioned. Along these lines the Tertiary deformation occurred, while many of the main lava extrusions burst from north-south vents along pre-Tertiary

[17] U. S. Geol. Surv., Bull. no. 308, pp. 32–36 and 40–42, 1907.

[18] U. S. Geol. Surv., Prof. Pap. 42, 1905.

[19] Geol. Expl. of the 40th Parallel, vols. I and II, 1877 and 1878.

[20] 21st Ann. Rept., U. S. Geol. Surv., pt. II, pp. 191–226, 1900.

mountain ridges. The first lava to outflow was a rhyolite, which was followed by monzonites and acidic andesites, in part intrusive bodies. Next was an important and probably long erosion interval, followed by a mighty extrusion of rhyolite, which equals or exceeds in bulk the basalt outflow of late Pliocene and early Pleistocene time. The ryholite in turn was followed by andesites and dacites, and these by unimportant rhyolites, immediately preceding the deposition of the Siebert lake beds in the Pahute Lake. It was probably during this general period that the most important ore deposits in the Tertiary rocks were formed, presumably by waters heated by the still-hot magmas. Between the outflow of the rhyolite and the formation of the Pahute Lake erosion was probably continuous, partially accounting for the formation of the lake basin which in the main, however, originated through orogenic sinking that was possibly, in part, consequent on adjustments due to the extrusion of immense bodies of lava, a hypothesis suggested by Spurr. The Pahute Lake covered practically the whole area surveyed, although the presence of coarse conglomerates in the Kawich and Amargosa ranges and the Bullfrog Hills indicates that rugged islands rose above the surface of the lake. Wherever the former shores of the lake are now seen it is evident that the surface of the older rocks was uneven and that each island was surrounded by islets. The climate must have been moist and the presence of fossilized wood in the lake beds shows that trees flourished near its shores. While the lake was thus for the most part fresh, periods of aridity alternated with those of comparative humidity, and the lake or portions of it were partially dissected, permitting the local precipitation of limestone, gypsum, and boron minerals. Volcanic flows and explosive eruptions of rhyolitic materials occurred at various times during the existence of the lake. The Pahute Lake was destroyed in part by the increasing aridity of the climate and in part by deformation, which was accompanied and immediately followed by the extrusion of rhyolite. By this deformation the whole area was uplifted with attendant southward tilting, which accounts for the relatively low altitudes occupied by the Siebert lake beds in the southern portion of southwestern Nevada. Furthermore, the deformation, by differential uplift, blocked out the mountain ranges as they now appear and formed many of the inclosed valleys by broad folding and warping. Death Valley was at this time first outlined, though it was depressed later, probably in the late Pliocene or early Pleistocene time, by block faulting.

Extensive erosion followed and before the end of Pliocene time it had reduced the surface to mature and comparatively gentle topography. In restricted areas the Pliocene-Pleistocene basalt appears to have flowed upon a local peneplain. In late Pliocene time the climate was moist and a shallow lake probably covered a considerable area in the vicinity of Goldfield. The older alluvium, a formation widely distributed over the area, may be considered as deposits of the waning stages of this lake period in the inclosed valleys. Towards the end of this period the basalt extrusion reached its climax. Uplift accompanied by normal faulting and folding followed the deposition of the older alluvium, and at this time erosion appears to have been very active.

In recent time the erosion characteristic of arid lands has partially

filled the inclosed valleys with bowlders, gravels, and sands—debris from the wasting mountains—and the process is still going on (pp. 40–42).

As far as the continental area is concerned, the bases of tentative correlations—aside from the Rosamond whose fossils prove its upper Miocene age—are the epochs of deformation, volcanism, and erosion which appear to have been contemporaneous in that region and to have had as products sediments and lavas of lithologic similarity. We do not as yet know the relations of the Rosamond terrestrial fauna with the marine faunas of the southern Coast ranges, but the general age of the faunas gives us a datum plane upon which a tentative correlation may be begun, while diastrophic events in the two provinces seem to be broadly contemporaneous. The long period of Fernando deposition may be complementary to the first cycle of post-Miocene erosion in the interior, as both of these processes seem to require a fairly long period during which diastrophism was quiescent. The present orography of the southern Great Basin has probably come into being as the product of mountain-making movements of a date posterior to the later part of the Pliocene.

SUMMARY

The oldest rocks yet known in the western Mohave Desert are metamorphosed sediments, intruded by later plutonics of a general granitic composition. The gneiss and schist near the town of Barstow possibly belong to the older series. The intrusive granitic rocks were in places laid bare by erosion and on their eroded and weathered surfaces were laid down lavas and thick series of arkosic sediments, named the Rosamond Series by Hershey. The lavas and sediments were in places contemporaneous. In the two widely separated exposures of the Rosamond arkosic sediments in the Barstow syncline and in Red Rock Cañon, fossils of upper Miocene age were found. It is thought to be most probable that an epoch of mountain-making immediately preceded or was contemporaneous with the deposition of the Rosamond, which apparently shows all the evidences of its origin from nearby recently uplifted land areas. It is also considered most probable that an arid climate, essentially similar to that of the present-day Mohave Desert, prevailed

during the time of Rosamond deposition. Fresh-water and saline lakes existed, however, during at least a portion of Rosamond time, as is indicated by the presence of fossil remains of fresh-water pond or lake gasteropods and by interbedded deposits of limestone, gypsum, and boron minerals. After the Rosamond was deposited its strata were tilted, folded, and faulted by diastrophism which probably followed shortly after the epoch of Rosamond sedimentation. The less competent beds were deformed by close folding and overthrusting, but in general rather open, low folds were formed, accompanied either by upthrust or normal faults. A long-continued period of erosion followed, during which the cycle of erosion advanced in places to the stage of peneplanation, although it is not yet certain whether a general peneplain was developed throughout the region or whether a humid or an arid climate existed during the erosion cycle. Near the end of the erosion period volcanic activity broke out anew and for the last time. Evidence of this later volcanism has not yet been found in the westernmost Mohave Desert, but it is common in the eastern Mohave Desert and in the Great Basin to the east. The long period of quiescence and erosion was closed by an epoch of mountain-making during which the present mountain ranges of the region were formed. The present orography and topography is a joint product of the effects of this uplift and of the erosion consequent to the uplift. It is held that no indubitable evidence of recent climatic change has yet been secured in the western Mohave Desert.

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BIBLIOGRAPHY

1856. Blake, W. P., Geological report, Expl. and surv. for a railroad route from the Mississippi River to the Pacific Ocean. Vol. 5, Pt. II.

1875. Gilbert, G. K., Report on the geology of portions of Nevada, California, and Arizona, examined in the years 1871 and 1872, Geogr. and Geol. Expl. and Surv. west of the 100th meridian. Vol. III.

1887. Lindgren, Waldemar, The Silver mines of Calico, California, Trans. Am. Inst. Min. Engrs., vol. 15, pp. 717–734.

1893. Storms, W. H., Report on San Bernardino County, 11th Ann. (1st Biennial) Rept. of the State Mineralogist, Cal. State Mining Bur., pp. 337–369.

1896. Fairbanks, H. W., Notes on the geology of eastern California, Am. Geol., vol. 17, pp. 63–74.

1901. Spurr, J. E., Origin and structure of the Basin Ranges, Bull. Geol. Soc. Am., vol. 12, pp. 217–270.

1902. Hershey, O. H., The Quaternary of southern California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 3, pp. 1–30.

1902. Hershey, O. H., Some crystalline rocks of southern California, Am. Geol., vol. 29, pp. 273–290.

1902. Hershey, O. H., Some Tertiary formations of southern California, Am. Geol., vol. 29, pp. 349–372.

1902. Campbell, M. R., Reconnaissance of the borax deposits of Death Valley and the Mohave Desert, U. S. Geol. Surv., Bull. no. 200; Eng. and Min. Journ., vol. 74, pp. 517–519.

1902. Bailey, G. E., The saline deposits of California, Cal. State Min. Bur., Bull. no. 24.

1903. Spurr, J. E., Descriptive geology of Nevada south of the 40th parallel and adjacent portions of California, U. S. Geol. Surv., Bull. no. 208.

1903. Campbell, M. R., Basin-range structure in the Death Valley region of southeastern California, Abstract: Science, n. s., vol. 17, p. 302; Sci. Am. Suppl., vol. 55, p. 22666; Am. Geol., vol. 31, pp. 311–312.

1903. Campbell, M. R., Borax deposits of eastern California, U. S. Geol. Surv., Bull. no. 213, pp. 401–405.

1904. Bailey, G. E., The desert dry lakes of California, Min. and Sci. Press, vol. 89, pp. 138, 161, 174, 192–193, 205–206, 222–223, 241–242, 255.

1905. Mendenhall, W. C., The hydrology of San Bernardino Valley, U. S. Geol. Surv., Water Suppl. and Irrig. Pap., no. 142.

1906. Bailey, G. E., The borax deposits of California, Min. World, vol. 24, pp. 4–5.

1907. Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California, U. S. Geol. Surv., Bull. no. 308.

1908. Mendenhall, W. C., Ground waters and irrigation enterprises in the foothill belt, southern California, U. S. Geol. Surv., Water Suppl. and Irrig. Pap., no. 142.

1908. Fairbanks, H. W., Report of the State Earthquake Investigation Committee upon the California Earthquake of April 18, 1906, Carn. Inst., Publ. no. 87, vol. 1, pt. I, pp. 43–47.

1909. Keyes, C. R., Borax Deposits of the United States, Trans. Am. Inst. Min. Engrs., no. 34, pp. 867–903.

1909. Keyes, C. R., American borax deposits, Eng. and Min. Journ., vol. 88, pp. 826–827.

1909. Wainewright, W. B., Borate deposits of California, Inst. Min. Engrs., Trans., vol. 37, pp. 156–162.

1909. Storms, W. H., Geology of the Yellow Aster mine, Kern County, California, Eng. and Min. Journ., vol. 87, pp. 1277–1280.

1910. Hess, F. L., Gold mining in the Randsburg quadrangle, California, U. S. Geol. Surv., Bull. no. 430, pp. 23–47.

1911. Merriam, J. C., A collection of mammalian remains from Tertiary beds on the Mohave Desert, Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 167–169.

—— Johnson, H. R., Water Resources of the Antelope Valley, California, U. S. Geol. Surv., Water Suppl. and Irrig. Pap. (Report in preparation.)

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CONTENTS

Introduction

There is assembled in the collections of the Department of Palaeontology at the University of California an extensive and highly interesting collection of vertebrate remains from the Pleistocene cave deposits thus far known to the state. The material was secured during the exploration of the caves by the immediate efforts of Dr. Wm. J. Sinclair and Mr. E. L. Furlong, working under the direction of Professor John C. Merriam. General accounts have been published by both Sinclair[1] and Furlong[2], giving the location of the caves, nature of the deposits and lists of determined species. The bird material from these collections forms the subject of the present paper.

Occurrence

The caverns yielding bird remains are three in number. Potter Creek and Samwel caves are in the lower region of the McCloud River in Shasta County, California. Both are limestone caverns of considerable extent. Hawver Cave is in Eldorado County and is likewise of limestone origin. All three localities have present elevations between 1300 and 1500 feet above sea level and lie in the same faunal zone as determined by the distribution of Recent vertebrates. The Pleistocene age of the deposits is indicated by the fact that about thirty per cent of the mammalian species represented are at present extinct. *Elephas, Mastodon, Euceratherium, Megalonyx, Equus, Camelus,* and *Arctotherium* appear among the genera which are either extinct or are no longer represented in this region. Students of the mammalian fauna consider that the indications point to the greater age of the Potter Creek deposits although, as noted below, the evidence furnished by the avian remains is somewhat to the contrary.

The specimens obtained were in many cases badly fractured

[1] Sinclair, W. J., Univ. Calif. Publ. Am. Arch. Ethn., vol. 2, pp. 1–27, 1904.

[2] Furlong, E. L., Am. Jour. Sci., vol. 22, pp. 235–247, 1906; and Science, n.s., vol. 25, pp. 392–394, March 8, 1907.

or were gnawed by rodents before being unearthed, otherwise the preservation is generally good, since the factor of weathering is reduced to a minimum. As suggested by Sinclair, the method of introduction of the bones is not easy in all cases to determine. The great preponderance of birds belonging to ground-dwelling species is at once noticeable. None of these bones occur in their proper anatomical relations in the deposits. This condition suggests that their bodies were either brought in as the prey of predatory forms or else swept in by currents of surface drainage. A number of owls and vultures also occur, both of which groups commonly resort to caverns as places of abode. Their remains, deposited in the outer chambers of the caverns, would readily be swept on into more remote recesses by currents of water. The anserine remains doubtless represent prey carried into the cavern mouth by predatory forms such as the duck hawk (*Falco peregrinus*) which in turn left its bones in a similar position.

Record of Species

CATHARTES AURA (Linnaeus)

The remains representing this species are somewhat fragmentary, yet are in each case perfectly determinable. An ulna, a radius and a metacarpal are practically perfect and agree absolutely with the corresponding parts of the Recent specimens at hand. The single specimen of the species from Samwel Cave is represented by the distal end of a radius only; this part is however markedly different from the same portion of the skeleton in *Catharista*. The fragment is certainly of the genus *Cathartes*, and there appears no reason for considering the species as different from the existing *C. aura*. The manubrial part of a sternum and the distal end of a humerus represent the species in Hawver Cave.

The reason for the greater abundance of the species in Potter Creek Cave is hard to determine. Some local condition must have been the determining factor and not a scarcity of the species in the region of Samwel Cave. The mammalian remains suggest that the Potter Creek deposits represent an earlier time than those of Samwel Cave. *Cathartes* was evidently abundant during

the formation of the former deposits and it likewise is one of the abundant forms of to-day. Its scarcity in the Samwel Cave deposits was due probably to some one of the factors which brought about the entombment of the Samwel Cave remains.

CATHARISTA SHASTENSIS, n. sp.

Type specimen no. 8603, Univ. Calif. Col. Vert. Palae., tarsometatarsus from Potter Creek Cave, California. General characters of *Catharista occidentalis* Miller, but more robust; foot rotated inward upon the shaft. Comparison is here made with an average specimen of *C. occidentalis* from Rancho La Brea.

Fig. 1. *Catharista shastensis,* n. sp. Tarsometatarsus no. 8603, Pleistocene of Potter Creek Cave, Shasta County, California. Anterior face, approximately natural size.

The two specimens of the tarsometatarsus of *C. occidentalis* and *C. shastensis* are much the same in osteological characters. In total length the cave form is but five-tenths millimeters the shorter, a fact which greatly facilitates the comparison of proportions. Seen from in front, the most striking character afforded by the new form is the greater degree of robustness. In the head region, greater width increases the bluntness of the intercotylar tuberosity and the roundness of the dome-shaped cavity into which the proximal foramina open, as well as the width of the septum between these two foramina.

The shaft is much wider at its middle portion, so much so that the graceful taper toward a narrowest point slightly below the middle, that is seen in *C. occidentalis* is entirely lost. As noted in a study of the condors,[3] the tarsometatarsus of the young cathartid seems to differ from that of the adult individual by its greater slenderness of shaft in proportion to the width of the articular surfaces. The natural objection that the type specimen of the proposed new form might merely represent a more mature individual is controverted by the fact that its proximal foramina are less completely closed than in the specimen of *C. occidentalis* with which it is compared, a condition indicative of youth rather than of age in the individual.

The elevated inner border of the anterior face of the bone in *C. shastensis* drops backward as it passes down the shaft, thus giving the appearance of an inward rotation of the foot upon the shaft. This condition is more marked in the form under discussion than it is in *C. occidentalis.* Other differences are

[3] Miller, L. H., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, p. 1, 1910.

those of proportion and are best noted by a comparison of the dimensions recorded in the table below.

It is interesting here to note that the two extinct vultures from the cave region display a greater breadth of shank and foot than do their nearest relatives from the asphalt or from the Recent North American fauna, and although large series of specimens have been employed for comparison in each case, there is no intergradation in this character. In the case of the genus *Catharista*, the asphalt form is differentiated from the Recent *C. urubu* in the same respect, thus the three species, *shastensis*, *occidentalis* and *urubu*, form a series successively less robust of tarsometatarsus.

The material assembled indicates at least eight and possibly fifteen individuals of the species. With the exception of some of the Gallinae, no other form is so abundantly represented in the cave collections. Thus the occurrence is such as to indicate the comparative abundance of the species in the Shasta region during the period of deposition of the cave deposits.

Like the last named species, *Catharista* is less abundant in the Samwel Cave than in the Potter Creek Cave. There are but three specimens referable to the genus in the Samwel Cave, and their specific identity is not absolutely certain. In so far as they are known they correspond with the specimens of similar parts of true *C. shastensis* from Potter Creek Cave. Two fragmentary specimens from Hawver Cave are likewise ascribed with some reserve to this species.

Table of Measurements of *Catharista shastensis* and *C. occidentalis*

	C. occidentalis	*C. shastensis*
Tarsometatarsus—		
Total length	83.5 mm.	83.0
Greatest transverse diameter through head	16.0	17.4
Least transverse diameter of shaft	7.2	8.7
Greatest transverse diameter through trochleae	17.0	17.9
Greatest sagittal diameter through head	11.8	13.3
Sagittal diameter of shaft at middle point	5.9	6.9
Sagittal diameter of middle trochlea	10.8	10.6
Transverse diameter of middle trochlea	7.3	7.3
Humerus—		
Length from distal tubercle of pectoral crest to depression for brachialis anticus	56.4	59.5
Anteroposterior diameter of shaft at middle	11.6	12.4
Dorsiventral diameter of shaft at middle	9.7	9.8

GYMNOGYPS AMPLUS, n. sp.

Type specimen no. 9834, Univ. Calif. Col. Vert. Palae. Right tarsometatarsus from Samwel Cave. Tarsometatarsus very broad as compared with *Gymnogyps californianus* (Shaw); foot set inward on the shaft so that the median line of the shaft falls outside the center of the foot.

The establishment of this new form of condor is based on its comparison with a single Recent specimen in addition to a series of fourteen tarsometatarsi from the Pleistocene of Rancho La Brea, in which beds the bird occurs abundantly in a phase considered to be identical with the Recent species.[4] In this splendid series there is no individual which approaches in breadth of shank the dimensions displayed by the specimen here described. It is to be expected that a bird of the large size to which the condor grows would vary to a considerable degree. However, the extremes of variation exhibited by the series referred to above fail by a wide margin to include the cave form within its limits. As mentioned also in the previous discussion of that series, the difference between *Sarcorhamphus* and *Gymnogyps* as displayed by the tarsus is almost entirely one of relative width. *Cathartes, Gymnogyps, Sarcorhamphus*, and *Catharista* form a graduated series in this respect, passing from broader to narrower tarsus. The species here proposed displays a degree of flattening equal to or in excess of that seen in *Cathartes*.

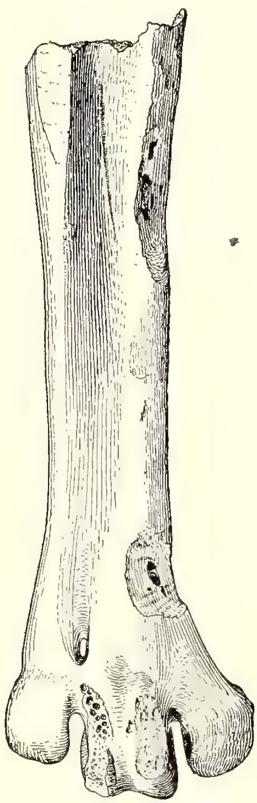

Fig. 2. *Gymnogyps amplus*, n. sp. Tarsometatarsus, no. 9834, Pleistocene of Samwel Cave, Shasta County, California. Anterior face, approximately natural size.

Unfortunately the proximal end of the tarsometatarsus is not preserved,

[4] Miller, L. H., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 1–19, 1910.

hence the characters of the hypotarsus, the intercotylar tuberosity and the tibial articulations remain undeterminable.

There appear in the Potter Creek Cave collection the remains of a condor the exact identity of which is not determinable. These bones, ten in number, are all fragmentary. The size of the form, as judged from the coracoid and humerus, is in excess of *Gymnogyps californianus*. Since the suggestion conveyed by the robust tarsus of *G. amplus* is that of a large species, the remains from Potter Creek are tentatively assigned to the latter species.

MEASUREMENTS

	G. californianus fossil No. 12161	*G. californianus* Recent No. 201	*G. amplus* No. 9384
Tarsometatarsus—			
Least transverse diameter of shaft	13.7 mm.	14.0	16.0
Anteroposterior diameter of shaft at middle point	10.0	8.6	11.0
Transverse diameter through trochleae	32.2	29.6	32.8
Transverse diameter of inner trochlea	9.0	8.0	9.3
Transverse diameter of outer trochlea	7.6	6.8	7.9

BUTEO BOREALIS (Gmelin)

The red-tailed hawk is represented in the Potter Creek collections only. The major part of a right humerus, a complete femur and an imperfect tibiotarsus, parts which, judging from their positions in the deposit, represent at least two different individuals, prove beyond question the identity of the remains. They compare perfectly with Recent specimens from California ascribed to the variety *Buteo borealis calurus.*

BUTEO SWAINSONI Bonaparte (?)

A fragmentary tarsometatarsus in the Samwel Cave collection is ascribed to this species. It is a typical buteonine shank, but appreciably slender as compared with *Buteo borealis.*

ARCHIBUTEO FERRUGINEUS (Lichtenstein)

The species is represented by one specimen only, a right humerus from Hawver Cave. The bone is broken away across the deltoid crest, the shaft and distal portion are perfectly preserved with the exception of the external portion of the radial

condyle. The characteristic region of the brachialis anticus is perfect, thus the identification becomes positive. The size is that of a large female specimen at hand.

ACCIPITER VELOX (Wilson)

Represented in the Samwel Cave collection by a single tarso-metatarsus which is perfect except for the extreme head. In size it is slightly stouter than a Recent juvenal at hand.

FALCO SPARVERIUS Linnaeus

A perfect tarsus and humerus in the Samwel collections and a humerus in the Potter Creek collection prove the presence of the species in a form osteologically identical with the existing phase.

FALCO PEREGRINUS Tunstall

Four specimens from Potter Creek Cave represent the species. The distribution of the material was such as to indicate at least three individuals.

GERANOAËTUS, sp.

In the collection from Hawver Cave there appears the humerus of a slightly built eagle almost identical in size with a specimen of the existing *Geranoaëtus.* The osteological characters of the genus are, as regards the humerus, more closely like those of *Haliaëtus.* The size is however too small to be included within the latter genus. In the asphalt of Rancho La Brea there appear several species of the smaller long-shanked eagles. The form under discussion may prove to belong to one of these Rancho La Brea species, but the characters obtainable from the distal end of the humerus are insufficient to differentiate it from the existing *G. melanoleucus* from South America. The bone from Hawver Cave is slightly larger than the single specimen of the South American form at hand, and the type tarsus of *Geranoaëtus grinnelli* from Rancho La Brea is likewise larger than the existing form. The Hawver Cave specimen does not however display any osteological characters which would distinguish it from the existing species.

There also appears in the same collection a coracoid of a size

slightly smaller than the Recent specimen of *G. melanoleucus* at hand which displays also a slight difference in the disposition of the pneumatic foramina. The two specimens probably belonged to birds of the same species.

Additional material of the Recent species of long-shanked eagles from South America may later make it possible to define the cave form as to species. It does not seem wise at present, however, to do so.

BUBO VIRGINIANUS (Gmelin)

This owl is represented in a phase perfectly similar to the existing form in so far as osteological characters and size are concerned. A lower jaw, perfect except for the left angular and articular region, corresponds in every particular with a specimen of the western subspecies, *B. v. pacificus.* A humerus and two femora, though fractured at the ends, display characters sufficient to place them in this species. The species is represented only in the Samwel Cave collections.

BUBO SINCLAIRI, n. sp.[5]

Type specimen no. 7092, Univ. Calif. Col. Vert. Palae. Right tarsometatarsus, Potter Creek Cave; cotype no. 8952, a tibiotarsus from Samwel Cave. The species is characterized by its very large size. The great gray owl, *Scotiaptex nebulosa,* is generally conceded to be the largest of the American owls, and perhaps equals in size the largest known member of the group. The cave form was compared with a large female specimen of this species in the University of California Museum of Vertebrate Zoology and was found to be quite appreciably larger. The snowy owl, *Nyctea,* was also inferior in size to the fossil specimen.

On comparing the tarsi of *Bubo* and *Scotiaptex,* there are several points of difference which appear at once, though the size is almost exactly the same. In *Bubo* the shaft is much more curved, the axis being concave from without where that of *Scotiaptex* is almost perfectly straight. The outer border of the external articular face is raised higher, the supratendinal bridge is narrower, the gorge under it much broader, the papilla

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[5] This species is named in honor of Dr. Wm. J. Sinclair, who was actively connected with the early exploration of the Shasta caves.

of the tibialis anticus is higher up the shaft, and the outer toe much higher above the middle toe. In all these respects the cave form resembles the genus *Bubo* except that the characters of the foot are not determinable. The depressed region of the proximal end is very broad and open in its excavation, the papilla of the tibialis anticus is lower, but is not drawn out into a ridge as in *Scotiaptex.* The somewhat accentuated angle on the exterior border just opposite the osseous bridge seems due in part to a slight scar on the bone.

On the whole, the relationships of the form seem to be decidedly with *Bubo* rather than with *Scotiaptex.*

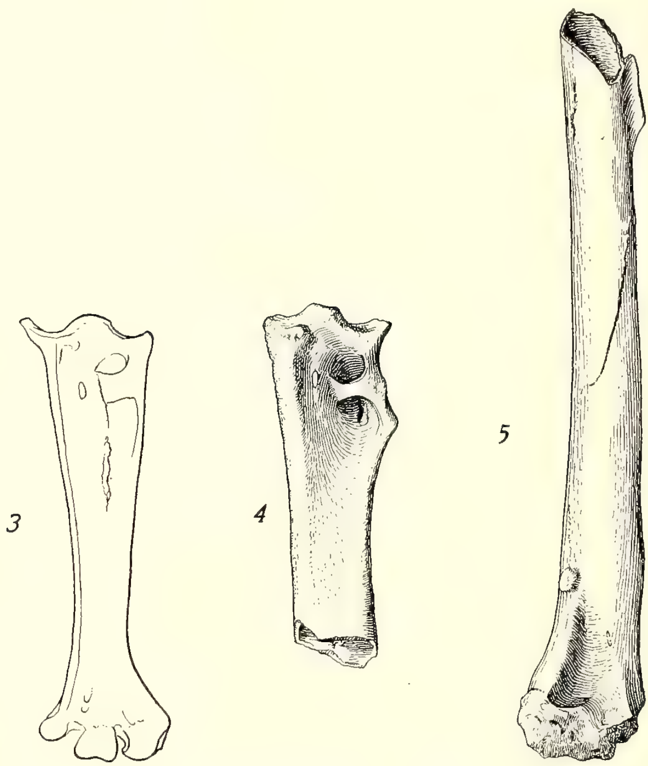

Fig. 3. *Scotiaptex nebulosa* (Forster). Recent. Tarsometatarsus, anterior face, approximately natural size.

Fig. 4. *Bubo sinclairi,* n. sp. Tarsometatarsus, no. 7092, Pleistocene of Potter Creek Cave, Shasta County, California. Anterior face, approximately natural size.

Fig. 5. *Bubo sinclairi,* n. sp. Tibiotarsus, no. 9852, Pleistocene of Samwel Cave, Shasta County, California. Anterior face, approximately natural size.

Measurements

	B. sinclairi	*B. virginianus*	*Scotiaptex nebulosa*
Tarsometatarsus—			
Total length		60.0	58.0
Transverse diameter of head	16.0 mm.	14.4	15.0
Least transverse diameter of shaft	10.5	7.8	8.1
Least anteroposterior diameter of shaft	6.1	5.1	4.7
Diameter through trochleae		17.6	17.0

OTUS ASIO (Linnaeus)

Known only by the shaft of a tarsometatarsus and the distal ends of two humeri occurring in the material from Potter Creek Cave.

ASIO WILSONIANUS (Lesson)

Two tarsometatarsi of this owl occur in the Samwel Cave collection. One lacks the trochleae and the other the extreme head, otherwise they are perfectly preserved and permit of exact determination. The two may have belonged to the same individual, as they were closely associated in the deposit and they correspond perfectly in size. The specimens are slightly less in size than a female of the Recent phase at hand, but the difference is no greater than is readily ascribable to difference in sex.

GLAUCIDIUM GNOMA Wagler

A perfect tarsometatarsus of this species occurs in the Samwel Cave material. Mr. Swarth of the University of California Museum of Vertebrate Zoology kindly dissected out the tarsometatarsus of a male specimen in the museum collection so that this rare material might be available for comparison. The cave form is identical in every respect with the Recent specimen except that it is slightly larger. Since the Recent specimen is a male and the difference in length is but one and one-half millimeters, the fossil form may be safely considered as a female of the same species.

MICROPALLAS WHITNEYI (Cooper)

A single perfect tarsometatarsus from Samwel Cave represents this species, which is now confined to the arid regions

farther southward. To find it here associated with the remains of *Dendragapus, Bonasa,* and *Branta* is certainly an interesting addition to our knowledge of the distribution of birds. The specimen is a typical strigine tarsometatarsus, the length of which corresponds perfectly with the recorded tarsal length of the Recent phase. Shufeldt figures the ligamentous skeleton of a specimen from the region of Tucson, Arizona,[6] which shows the general proportions of the tarsometatarsus though the details are obscure.

[6] Shufeldt, R. W., Am. Phil. Soc. Proc., vol. 39, p. 665, 1900.

BRANTA CANADENSIS (Linnaeus)

A single nearly perfect carpometacarpus occurs in the Potter Creek collection. The size is that of the Recent *B. c. canadensis.*

INDETERMINATE ANSERINES

Four imperfect specimens representing three anserine species of different sizes were found in the Samwel Cave deposits. The characters of the bones are not sufficiently well shown to warrant their assignment to any particular genus.

MELEAGRIS, sp.

There appear in the Potter Creek deposits, eight specimens of a meleagrine form, the species of which is not determinable from the material obtained. An almost perfect humerus and the major part of a coracoid are the only specimens at all well preserved. These show the bird to be *Meleagris* and not *Pavo.* The size is that of a female *Meleagris ocellatus* from Guatemala. The characters of the humerus are intermediate between those of *M. ocellatus* and *M. gallopavo* (domestic). In the absence of a larger amount of material both of the fossil and the Recent species, the specific designation of the cave form is left in question.

DENDRAGAPUS OBSCURUS (Say)

No less than one hundred and fourteen specimens from the Samwel and Potter Creek caves are ascribed to this species. With the exception of seven coracoids, all are limb bones, some in a perfect state of preservation. For comparison a specimen

of an adult female was loaned by the University of California Museum of Vertebrate Zoology. The uniformity of the material in regard to size is quite sufficient to include all under the one species *D. obscurus,* which is found in the locality at the present time.

DENDRAGAPUS, sp.

There appear among the grouse remains in the collection a large number of specimens of unusual size. The closest relationship seems to be with *Dendragapus,* from which the form differs in its great robustness and in the slight detail of the head of the tarsometatarsus. The Recent material at hand includes only a female of *Dendragapus,* hence the range of variation due to sex and age is unknown to the writer. Until further Recent material is obtained the identity of these larger specimens remains in doubt.

BONASA UMBELLUS (Linnaeus)

This species is at present distributed along the humid coast region of the continent as far south as the latitude of the Shasta region. It is however not recorded from localities so far inland in Recent time. It is of interest, then, to find in the Potter Creek Cave two very perfect specimens referable to this species.

OREORTYX PICTA (Douglas)

This quail is represented by eighteen specimens, all but four of which are from Hawver Cave. Comparison was made with a specimen from the University of California Museum of Vertebrate Zoology and the identity found to be unquestionable.

LOPHORTYX CALIFORNICA (Shaw)

This species is represented in the Hawver Cave deposits only, but here it is the most abundant of avian species, seventeen specimens of wing and leg bones making the identification complete.

In number of individuals, the group Gallinae far surpasses all of the others combined. There are in the cave collections some two hundred and seventy individual bird bones that are determinable. Of these one hundred and sixty-eight are assigned

to the Gallinae. The number of species is however limited to six, and of these one contains one hundred and fourteen specimens. Of the six species, three are grouse, two are quail, and one a large meleagrine form.

One very noticeable fact is that the genus *Lophortyx*, embracing the varieties of the California quail, is entirely wanting in the collections from Potter Creek and Samwel caves, while *Oreortyx* is represented by only four specimens from Potter Creek Cave. It seems hardly probable that this lack of quail remains can be due to the conditions of interment, but rather to a scarcity of the species in the immediate vicinity during the time of deposition. A predatory species which would carry the remains of grouse into the cave would prey also upon the quail, which are slightly smaller and of similar habit. The greater fragility of the bones of the smaller form seems an inadequate explanation in the presence of the remains of such forms as *Colaptes, Cyanocitta, Glaucidium, Micropallas*, and *Falco sparverius.*

The accidental introduction by washing from the surface or through blundering of the animal causing its death by falling into an open fissure would be more effective in the introduction of quail remains than in the case of the non-terrestial forms *Colaptes* and *Corvus*, both of which are forms represented in a well-balanced fauna by fewer individuals as a rule than is the case with the quail.

The great abundance of quail remains in Hawver Cave would suggest a later time of deposition for these deposits.

COLAPTES CAFER (Gmelin)

This species is represented in all three caves by the very characteristic ulna with its pronounced olecranon process and prominent papillae for the attachment of the secondaries.

CORVUS CORAX Linnaeus

The species is found in Hawver Cave only, where it is represented by twelve specimens, the remains of several individuals if the character of the specimen may serve as an indication.

CORVUS BRACHYRHYNCHOS Brehm

There occur in the Potter Creek collection a nearly perfect humerus and the distal end of a tibiotarsus which correspond perfectly with the existing phase of this species. The position in the deposit indicates their origin from two different individuals.

CYANOCITTA STELLERI (Gmelin)

A single perfect tarsometatarsus represents this species of jay in Samwel Cave. In comparing with a specimen of the subspecies *C. s. carbonacea,* the only noticeable difference lies in the slenderness of the fossil. The length is exactly the same, the degree of slenderness is so slight as to seem negligible in the determination of the species. In Hawver Cave there occur four specimens which show the same slenderness of build.

EUPHAGUS CYANOCEPHALUS (Wagler)

Seven specimens of this species occur in the collections from Hawver Cave. Several limb bones and a coracoid serve to establish the specific identity. This bird is entirely wanting in the deposits of the other caves.

TABULAR VIEW OF THE CAVE FAUNAS

Illustrating number of specimens of each species found in the different caves.

	Potter Creek Cave	Samwel Cave	Hawver Cave
Cathartes aura (Linnaeus)	9	1	2
Catharista shastensis, n. sp.	26	3	7
Gymnogyps amplus, n. sp.	10	2	....
Buteo borealis (Gmelin)	3	....	....
Buteo swainsoni Bonaparte(?)	....	1	....
Archibuteo ferrugineus (Lichtenstein)	....	....	1
Geranoaëtus, sp.	....	....	2
Accipiter velox (Wilson)	....	1	....
Falco peregrinus Tunstall	4	....	....
Falco sparverius (Linn.)	1	2	....
Bubo virginianus (Gmelin)	....	4	....
Bubo sinclairi, n. sp.	2	3	....
Otus asio (Linnaeus)	3	....	....
Asio wilsonianus (Lesson)	....	2	....

	Potter Creek Cave	Samwel Cave	Hawver Cave
Glaucidium gnoma Wagler	....	1	....
Micropallas whitneyi (J. G. Cooper)	....	1	....
Branta canadensis (Linnaeus)	1	....	....
Anserine indeterminate, no. 1	....	1	....
Anserine indeterminate, no. 2	....	1	....
Anserine indeterminate, no. 3	....	2	....
Meleagris, sp.	8	....	....
Dendragapus obscurus (Say)	22	92	....
Bonasa umbellus (Linnaeus)	2	....	....
Oreortyx picta (Douglas)	2	....	14
Lophortyx californica (Shaw)	....	....	17
Colaptes cafer (Gmelin)	1	2	3
Corvus brachyrhynchos Brehm	2	....	....
Corvus corax Linnaeus	....	....	12
Cyanocitta stelleri (Gmelin)	....	2	4
Euphagus cyanocephalus (Wagler)	....	....	7

Transmitted July 8, 1911.

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

BULLETIN OF THE DEPARTMENT OF

GEOLOGY

Vol. 6, No. 17, pp. 401-402 Issued November 1, 1911

A FOSSIL BEAVER FROM THE KETTLEMAN HILLS, CALIFORNIA

BY

LOUISE KELLOGG

BERKELEY

THE UNIVERSITY PRESS

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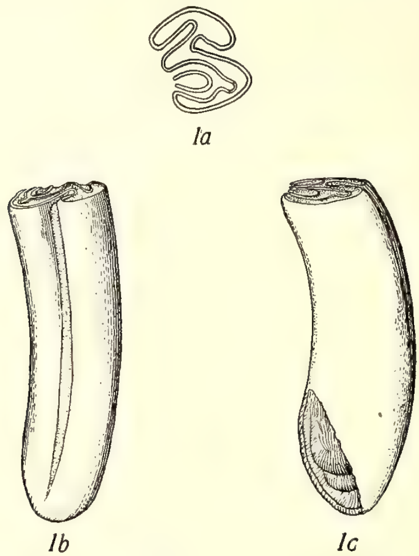
BY

LOUISE KELLOGG

The finding of a fossil beaver tooth in a formation much earlier than any in which this animal has hitherto been found in this country is the work of Mr. W. H. Ochsner, of Palo Alto, California. He discovered the tooth at the north end of the Kettleman Hills, Fresno County, California, in a formation which he considers Middle Etchegoin, corresponding approximately to the late Miocene or early Pliocene, and kindly sent the specimen to the palaeontological collection of the University of California. Up to this time the earliest known occurrence of the true beaver, *Castor*, in America, was in the Pleistocene of the Silver Lake region, Oregon, so that the finding of this genus in beds as early as the late Miocene or early Pliocene is an interesting and important discovery.

Although only the one tooth, M^2, no. 19408, is available, it possesses one character, namely, that the anteroposterior diameter is greater than the transverse, which is considered sufficient ground to make it, at least tentatively, a new species, *Castor californicus,* and it may be presumed that, if more material were available from the same source, this would exhibit additional characters to further establish the new species. The tooth is remarkably close in pattern to those of the various species of *Castor* found on the Pacific Coast, but in all of the Recent skulls examined the transverse diameters of the molars is either the same as the anteroposterior diameter or greater than this diam-

eter, while the fossil form shows a distinct increase in the anteroposterior diameter over the transverse. Comparison with M^3 of *Castor neglectus* Schlosser, from the Bohnerzen of Melchingen, Germany, exhibits some similarity of pattern, and that tooth also is one in which the anteroposterior diameter exceeds the transverse, but it is M^3, and shows a narrowing posteriorly, which makes it decidedly different in shape from *Castor californicus,*



Figs. 1*a* to 1*c*. *Castor californicus,* n. sp., Etchegoin formation, Kettleman Hills, California; all figures twice natural size. Fig. 1*a,* occlusal view; fig. 1*b,* inner side; fig. 1*c,* posterior side.

although there is but a slight difference in the diameters. *Dipoides problematicus* Schlosser, from the same locality as *Castor neglectus,* is allied to these two *Castor* forms in pattern, but it is much smaller. From *Eucastor* Leidy, *Castor californicus* differs distinctly in having three enamel folds in its outer wall instead of the one characteristic of that genus and of *Trogontherium.*

MEASUREMENTS, M^2, NO. 19408

Anteroposterior diameter	6.8 mm.
Transverse diameter	5.8

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BULLETIN OF THE DEPARTMENT OF

GEOLOGY

Vol. 6, No. 18, pp. 403-412 Issued November 1, 1911

NOTES ON THE GENUS DESMOSTYLUS OF MARSH

BY

JOHN C. MERRIAM

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CONTENTS

INTRODUCTION

The peculiar mammalian genus *Desmostylus* described by Marsh[1] as a sirenian is of considerable interest to palaeontologists, as it represents a peculiar combination of proboscidean and sirenian characters. It is, however, one of the most imperfectly known of the Pacific Coast vertebrate forms, the total amount of American material available for study including only a few teeth and some scattered fragments of skeletal elements. Recent discoveries seem to show that *Desmostylus* may be a valuable horizon determiner in geologic work in California, and may also have some importance in geological correlation between America and Asia. It has, therefore, seemed desirable to bring together all of the information available concerning this form, in the hope that such a statement may assist in the accumulation of further data relating to its structure and range.

[1] Marsh, O. C., Am. Jour. Sc., vol. 35, pp. 94 to 96, 1888.

OCCURRENCE

Particular attention has already been called[2] to the fact that all *Desmostylus* material of which definite information could be obtained has been found in marine beds. This statement is, however, not in accord with that of Marsh, according to whom the type material was found in association with remains of mastodon, camel, a large edentate, and one or more species of horse. Since the publication of his note on this subject it has been the writer's privilege to examine Marsh's type of *Desmostylus,* through the courtesy of Professor Richard S. Lull, of Yale University. Contrary to the statement in Marsh's description, it was found that the original label describes the type of *Desmostylus* as coming from Contra Costa County, California, where it apparently occurred in association with marine Miocene invertebrates. One of the specimens is embedded in rock similar to that of one phase of the marine Miocene of middle California. The only objection to considering *Desmostylus* as a marine form has, therefore, disappeared. It is to be presumed that the animal may have occupied the mouths of rivers and could, therefore, be found in estuary or even in river deposits.

Within the last few years a number of occurrences have come to light which indicate collectively that *Desmostylus* is limited to a comparatively narrow geologic zone of the Tertiary, and is presumably of value as a means of correlating widely separated deposits.

Numerous fragments of *Desmostylus* teeth have been found by Mr. F. M. Anderson to the north of Coalinga, in the western part of the San Joaquin Valley, in beds designated by him as the Temblor formation. As nearly as can be determined, *Desmostylus* does not occur either above or below this zone in this region. A record of an occurrence corresponding to that described by Mr. Anderson was obtained by the writer some years ago from a specimen in the museum of the California State Mining Bureau. The location of this specimen is defined as Canoes Cañon, Sec. 33, T. 22 S, R. 16 E, Mt. Diablo Base and Meridian. As shown by the mapping of this region by Ralph

[2] Merriam. J. C., Science, n. s., vol. 24, p. 151, 1906.

Arnold and Robert Anderson, a strip of the Vaqueros formation, corresponding approximately to the Temblor of F. M. Anderson, crosses the higher side of this section. A tooth derived from this zone might be washed to any part of the section.

Farther to the south, on the west side of the San Joaquin Valley, F. M. Anderson reports *Desmostylus* at the Temblor horizon in the region of the Devil's Den. On the east side of the valley in the Kern region Mr. Anderson finds it again in beds corresponding to his Temblor formation of the west side of the valley.

Important discoveries of *Desmostylus* remains were recently made in the Vaqueros formation north of Coalinga by Robert Anderson, and by Robert Anderson and R. W. Pack of the U. S. Geological Survey. With the permission of the Director of the Survey, through the courtesy of Mr. Anderson and Mr. Pack, the writer had the opportunity of examining this material. The most interesting specimens comprise a fine molar tooth and a portion of a tusk. The cheek-tooth (figs. 1*a* and 1*b*) corresponds almost exactly in form and size to the second upper cheek-tooth of a skull described by Yoshiwara and Iwasaki from Japan.

Other occurrences of *Desmostylus* in southern California include a number of fragments of teeth obtained by Mr. W. L. Still of La Panza, San Luis Obispo County, and brought to the writer's attention by Professor A. C. Lawson. These specimens are considered by Professor Lawson as occurring in association with shales and sandstones near the Vaqueros formation. Another collection of *Desmostylus* teeth was obtained by Mr. C. H. McCharles from a belt of shale and sandstone about six miles northeast of Santa Ana, Orange County (see fig. 3). These beds are considered by those who have examined them as probably near the horizon of the Vaqueros.

The occurrence of the type specimen being indicated only as in Contra Costa County, it is not possible to determine certainly the horizon at which it was found. There is, however, in the Tertiary of Contra Costa County a zone corresponding to that in which *Desmostylus* is known to occur in the region farther south, and the nature of the matrix suggests that this specimen came from one of the horizons of the Miocene.

The best preserved specimen of *Desmostylus* in the University of California collection (figs. 2*a* and 2*b*) is unfortunately labeled only with the name of the donor, who is no longer to be found.

Considering all of the California occurrences of *Desmostylus* remains concerning which we have any reliable data, there seems good reason to regard it as probably characteristic of the Vaqueros or Temblor horizon, and presumably not occurring much if any higher than the faunal zone of *Turritella ocoyana*, which marks the upper limit of the Temblor or Vaqueros as commonly recognized.

Outside of the region of California the only occurrence of *Desmostylus* known in America is that of a tooth obtained by Professor Thomas Condon from the beach of Yaquina Bay in the northern half of the Oregon coast. This specimen evidently came from middle Tertiary beds which are exposed along the beach, but it is not possible to make certain of the exact horizon from which it was derived. As nearly as can be determined the tooth came either from beds recognized as Oligocene, or from some part of the Miocene. In as much as there are reasons for considering that the marine Oligocene of Oregon may correspond in age to the Temblor or Vaqueros of California, it is possible that the horizon of *Desmostylus* at Yaquina Bay is close to that of the definitely known occurrences in California.

Remains referable to *Desmostylus* are reported by Yoshiwara and Iwasaki[3] from the Tertiary of Japan. They occurred in a tuffaceous sandstone lying some distance above a horizon containing many marine shells generally considered to be of Miocene age. Associated with the *Desmostylus* bones were teeth of a shark (*Carcharias japonicus*), a marine shell (*Solen*), and impressions of some land plants. The presence of plants suggests that the deposits were formed near shore, and presumably near the mouth of a river. From such information as is available one might consider the Japanese *Desmostylus* as coming from Miocene beds.

Considering all of the evidence before us, it is clear that *Desmostylus* was a marine animal, which may have gone into

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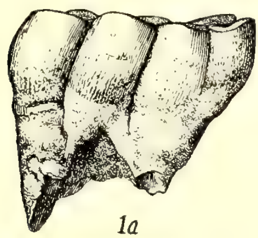
[3] Yoshiwara, S., and Iwasaki, J., Jour. Coll. Sc. Imp. Univ. Tokyo, vol. 16, art. 6, 1902.

the mouths of rivers; its known geographic distribution extended around the north Pacific from southern California to Japan; its geologic range in America is found in a zone near the base of the Miocene. As the time equivalence of the formations in which *Desmostylus* occurs is not yet fully understood, later study may show that the downward limit of range corresponds to the Oligocene or that the upper limit corresponds to middle Miocene.

DENTITION

The teeth of *Desmostylus*, as known from the Californian specimens (figs. 1*a* to 2*b*), consist of several pairs of high pillars



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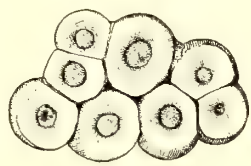

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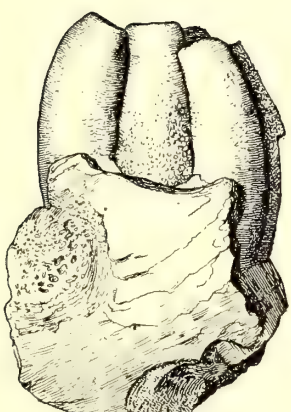
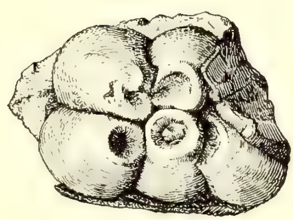


2a



2b

Figs. 1*a* and 1*b*. *Desmostylus*, sp. M^1, $\times$ ½. Lower Miocene, north of Coalinga (NW ¼ sec. 29, T. 18 S, R. 15 E). Collected by Robert Anderson. Fig. 1*a*, lateral view; fig. 1*b*, occlusal view.

Figs. 2*a* and 2*b*. *Desmostylus*, sp. M_1, no. 9091, $\times$ ½. California, exact locality unknown. Fig. 2*a*, lateral view; fig. 2*b*, occlusal view.

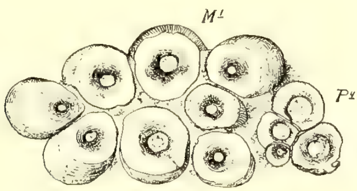
which are generally closely aggregated and nearly circular in cross-section. In some instances they are closely grouped and become angulated where they are in contact. The pillars are generally arranged in pairs set transverse to the longest diameter of the crushing face. In some cases three pillars are present in the transverse row. The average tooth comprises three pairs of pillars. In one specimen four transverse rows are present. In section (figs 1*b* and 3) the pillars are seen to consist of an extraordinary thick enamel layer and a comparatively small dentine body. The enamel resembles in general characters that of the teeth in members of the mastodon group. In wear the pillars usually show a very thick rim of enamel surrounding a small central pit worn into the softer dentine. With wear the size of the central dentine area increases until, in a half-worn tooth, its diameter may about equal the thickness of the enamel ring. In the field the teeth are most commonly found broken up into fragments of pillars.

Fig. 3. *Desmostylus*, sp. Fragment of a cheek-tooth showing thickness of enamel. No. 10015, natural size. Lower Miocene?, near Santa Ana, California. Collected by C. H. McCharles.

Of the known Japanese specimens very fortunately one includes a large part of a skull with a number of teeth in the jaws. In this individual there are three cheek-teeth shown in the upper jaws (figs. 4 and 11) and three in the lower (figs. 5 to 7). The anterior tooth in each jaw is much smaller than the tooth immediately behind it, and was considered by Yoshiwara and Iwasaki as P^4 in the upper jaw and P_3 in the lower jaw. The anterior cheek-tooth, P^4, of the upper jaw consists of four pillars of which the posterior pair are relatively quite small. The second upper cheek-tooth, M^1, is at least three times as large as P^4. It consists of eight large pillars, of which three form the anterior transverse row, two pairs form the second and third transverse rows, and a single pillar forms the posterior

segment of the tooth. A third upper cheek-tooth, M^2, not yet in function, is seen in the jaw bone behind M^1.

In the lower jaw (figs. 5 to 7) there is less difference between the first and second cheek-teeth than in the upper series. The first two teeth, considered by Yoshiwara and Iwasaki as P_3 and P_4, each consist of seven pillars, but P_3 is much the smaller tooth, and is short-elliptical instead of long-quadrate in cross-section.



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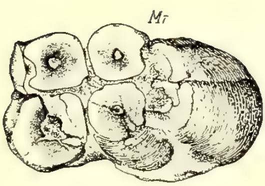

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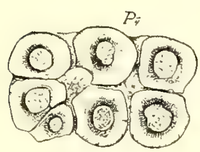

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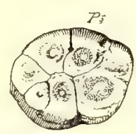

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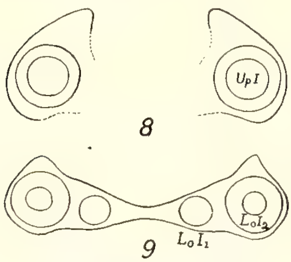
Figs. 4 to 7. *Desmostylus*, sp. Cheek-teeth in occlusal view, × ½. Miocene of Japan. Fig. 4, M^1 and P^4; fig. 5, M_1; fig. 6, P_4; fig. 7, P_3. (After Yoshiwara and Iwasaki.)

P_4 consists of three transverse rows of pillars with two each in the anterior and middle segments, and three in the posterior one. P_3 may be considered as having three transverse rows of two each with an isolated pillar at the anterior side of the tooth. The third lower cheek-tooth, M_1, consists of only six pillars arranged in three transverse pairs, but it is much larger than the second tooth, or P_4.

As the Japanese specimen evidently represents a young individual, it is not entirely certain how many cheek-teeth were present normally in the jaw of the adult animal.

In the specimen of *Desmostylus* described by Yoshiwara and Iwasaki there was a single pair of large tusk-like teeth in the upper jaw and two pairs in the lower jaw (figs. 10 and 11). The tusks were considered as incisors. The upper pair seems, however, in doubtful relation to the maxillary, and may represent canines, as also the posterior lower pair. The tusks are said to reach a length of at least twenty centimeters. They are circular in cross-section, and are entirely covered with a thick enamel (figs. 8 and 9).



Figs. 8 and 9. *Desmostylus*, sp. Incisors in cross-section in the jaws, × ¼. Miocene of Japan. Fig. 8, upper incisors; fig. 9, lower incisors. (After Yoshiwara and Iwasaki.)

As nearly as can be determined, the tusk fragment obtained by Robert Anderson and R. W. Pack from the Vaqueros formation of California corresponds in form and structure to the tusks of the Japanese specimen of *Desmostylus*. It was about eighteen inches long, and was completely covered with enamel. Only the tip was preserved in the collection examined by the writer. This fragment is about one inch in diameter at a point less than two inches from the tip. The enamel on this tooth is slightly roughened.

SKELETON

The skull of *Desmostylus* is known only through the specimen described from the Tertiary of Japan. The posterior region of the skull is broken away. The superior side from the frontals forward as represented in the illustration presented by Yoshiwara and Iwasaki (fig. 10) differs from all of the known sirenian forms. The premaxillaries completely surround the anterior narial opening, their posterior ends separating the acute anterior terminations of the nasal elements from the posterior border of the nares. The exact form of the nasals is not quite clear, but from the illustration they seem to extend backward between the anterior ends of the frontals. The maxillaries are large elements, forming a considerable part of the facial region.

In the large size of the nasals and maxillaries *Desmostylus* is more primitive than any other form referred to the Sirenia. The situation of the anterior narial openings seen here is dif-

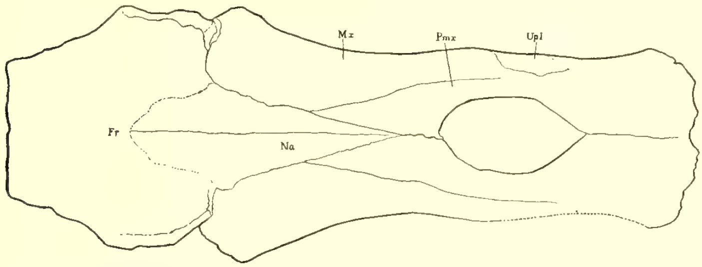


Fig. 10. *Desmostylus,* sp. Superior view of anterior region of the skull, × 1/6. Miocene of Japan. *Fr,* frontal region; *Na,* nasal; *Mx,* maxillary; *Pmx,* premaxillary; *Up I,* upper incisor. (After Yoshiwara and Iwasaki).

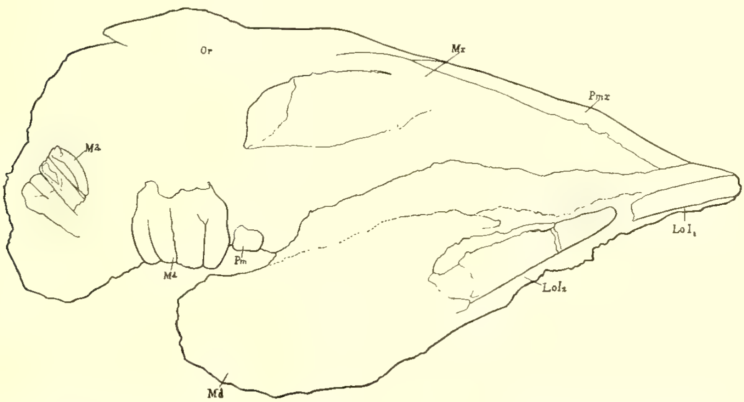


Fig. 11. *Desmostylus,* sp. Lateral view of a portion of the skull with the lower jaw, × 1/6. Miocene of Japan. *Pmx,* premaxillary; *Mx,* maxillary; *Or,* orbital region; *Pm,* fourth upper premolar; M^1, first upper molar; M^2, second upper molar; *Md,* mandible; *Lo* I_1, first lower incisor; *Lo* I_2, second lower incisor. (After Yoshiwara and Iwasaki.)

ferent from that in other forms of this order. The other characters of the skull are unfortunately not clearly shown in this specimen.

Fragments of ribs and vertebrae referable to sirenians have been found in the middle Tertiary of California, and some or

all of these remains presumably represent *Desmostylus*, but as yet it has not been possible to make certain of the relationships of these fragments.

SYSTEMATIC POSITION

The evidence before us indicates that *Desmostylus* represents a group which is to be included in the Sirenia. The characters of the skull and dentition suggest that when the whole skeleton is seen this genus may be found to differ from the known groups sufficiently to make necessary its reference to a family distinct from those thus far described. The peculiar characters of the skull and dentition of *Desmostylus* add somewhat to the evidence which has been held to indicate relationship of the Sirenia to the Proboscidea.

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THE ELASTIC-REBOUND THEORY OF EARTHQUAKES

BY

HARRY FIELDING REID

BERKELEY
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THE ELASTIC-REBOUND THEORY OF EARTHQUAKES*

BY

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Earthquake shocks have apparently occurred in all geologic ages, in the past as well as in the present. This is shown by the presence in the rocks of sandstone dykes, which have been explained as the filling up of earthquake cracks from above or below by loose sand, which afterwards became consolidated; and by the presence of faults, which is, in itself, evidence that shocks occurred when they were formed; for whenever there is a movement on a fault surface, it is always accompanied by an earthquake.

It is very easy to picture to ourselves the terrorizing effect of an earthquake shock to an uncivilized people; but the lack of records in prehistoric times, and even later among uncivilized people, accounts for the fact that the history of many serious and disastrous earthquakes has been wholly lost. Indeed, with the exception of a few countries, such as Japan and China, it is only within the most recent times that a complete record of the heavy shocks occurring in civilized regions has been kept; and, without doubt, many serious shocks in less known parts of the world's surface, even within the last two or three hundred years, have entirely escaped our notice. At the present time fairly complete lists of even the weaker shocks are kept.

* First of the Hitchcock Lectures delivered at the University of Cailfornia in the Spring of 1911. These lectures, with additions, will be published as a book.

Naturally enough great efforts were made to explain the causes of earthquakes. The very crude notions in ancient times, and among uncivilized people, have suggested the most extraordinary ideas. Among the semi-civilized and barbarous races we find the idea was prevalent that an animal of some kind existed below the ground whose movements caused earthquakes; the different races selected different animals, according to their tastes. In his interesting book on "Seismology," Professor Milne writes: "In Japan it was supposed that there existed beneath the ground a large earth-spider, or *jishin mushi,* which later in history became a cat-fish. . . . In Mongolia, the earth-shaker is a subterranean hog; in India, it is a mole; the Mussulmans picture it an elephant; in the Celebes there is a world-supporting hog; while in North America the subterranean creature is a tortoise." There were other futile attempts to explain earthquake phenomena during the period before the development of science. Science, as has been said, is merely systemized knowledge, and it is only by the use of scientific methods, that is, by a careful examination and comparison of the phenomena with known facts and principles, and by a systematic record of the results, that we can gradually approach, step by step, to a truer and more accurate knowledge of the facts.

It is hardly necessary for me to point out to this audience, the majority of whom were present at the time of the great earthquake of April 18, 1906, the general effects of a great earthquake and, moreover, they have been described in sufficient detail in several well-written books. I shall endeavor in these lectures to put before you, as clearly as possible, a conception of what actually takes place at the time of a tectonic earthquake, the nature and purposes of the instrumental observations at distant stations, the methods of study, the problems awaiting solution, and the revelations regarding the interior of the earth which earthquake study, up to the present time, has made.

Let me first, however, call your attention to the essential phenomena of earthquakes. It has long been recognized that earthquakes were due to a rapid to-and-fro motion of the earth, and that these vibrations were propagated from a center of disturbance. It has also been recognized for some time that these

vibrations must be of the nature of waves, elastic and not gravitational waves; and the question which presents itself to us is: what produces these waves? Their origin lies, of course, in the region of greatest disturbance, but its exact position and the causes which produce the disturbance are not so easily discovered. Many theories have been advanced. The earlier ideas, suggested largely by the outbursts of volcanoes, were that the earth was a fluid mass surrounded by a thin liquid crust floating upon it, and that movements of the fluid interior caused earthquakes in the crust. These vague notions have been rendered somewhat more precise by Pilar, who, in his book on "Abyssodynamik" in 1881, supposed that the crust was broken into sections by cracks which were inclined and not vertical, and that those blocks which had a broader base and contracted upwards were raised, and the intervening blocks lowered, under the action of gravity and the pressure of the fluid interior, whenever the disturbance allowed this readjustment, and in this way earthquakes were produced. The idea that volcanic outbursts were always accompanied by earthquakes and that generally the regions of the earth where volcanoes were common were also regions of many earthquakes, led to the belief that these were but two phases of the same phenomena, and that earthquakes themselves were due to explosions in the fluid interior. The downfall of rock in caverns was, one hundred years or so ago, looked upon as the most important cause of earthquakes, but we shall see that this cause is insufficient to bring about strong earthquakes and indeed it has gradually received less and less support. The ideas that many earthquakes are independent of volcanic action and that they are due to movements of some kind in the crust of the earth became stronger, and in 1850 C. F. Naumann divided earthquakes into two classes, the *volcanic* and the *tectonic;* the first being due to volcanic explosions and the second to movements in the rock-mass. The importance of this latter cause has become more and more apparent, so that now we feel quite certain that all the really great earthquakes are of the tectonic class, and that earthquakes connected with volcanic outbursts are of comparatively little importance. It is always found that volcanic earthquakes, although they may

be very violent in the immediate neighborhood of their origin, die out at a very short distance from it, and, indeed, this is one criterion actually used to determine in which class a particular shock should be put.

Researches in science are like explorations in an unknown country. The careful explorer maps his route and determines carefully his position with respect to known places from which he starts; he gradually maps the country he traverses, determining the positions of the mountain ranges, the courses of the rivers and so on. He may from some vantage ground obtain a glimpse of distant regions and of broad rivers, and he may make a fairly good guess as to what part these rivers play in the drainage of the country; but this is merely a guess, and he must proceed step by step, laying down his position and the positions of the topographic features in order to get a true and exact knowledge of the interior, and a correct conception of the courses of these rivers. So it is in science. At certain moments we form conceptions of phenomena which may, or may not, be correct. We must not be satisfied with this, but by patient reasoning, by careful observation and, where possible, by experiments, we must gradually weed out the error and prove the truth and thus establish a new starting point for future advances. It is by such methods and only by such methods that we can increase our knowledge of earthquakes.

Let us then examine what occurs at the time of earthquakes and by a careful comparison with known physical laws, try to discover the actual process of events. We cannot do better than to take for our example the great California earthquake of April 18, 1906, which occurred a little after five o'clock in the morning, and produced such disastrous results. Great praise is due to the energy of the scientific men of the Pacific Coast, who promptly induced the Governor of the State of California to appoint a commission to investigate the earthquake, the necessary funds being supplied by the liberality of the Carnegie Institution of Washington. The great mass of facts collected, together with a discussion of them, are contained in the report of the Commission, which was published by the Carnegie Institution. It is impossible and, indeed unnecessary, to repeat all these

interesting observations and it will only be necessary to summarize some of the most important which lead directly to a clearer conception of the forces which produced the shock.

A few days before the shock Professor Branner's students had been working in the region of the San Andreas fault and after the shock they quickly realized that there had been a new movement on this line. Reports from other places along the same fault showed that displacements had also occurred there, and the more thorough exploration of the whole region brought out the fact that at the time of the earthquake there had been a slip on the San Andreas fault over a distance of 270 miles, in which the two sides of the fault had been displaced relatively to each other by amounts varying from a maximum of twenty-one feet to an unascertained minimum, but which, of course, must have disappeared entirely at the ends of the fault. The movement was practically horizontal and although it is probable that there was some vertical component, varying in different parts of the fault, this has not been made out with satisfactory accuracy. The discovery of this dislocation emphasized the horizontal slip on faults, a fact which, although not unknown before, had not received its merited attention. Text-books on geology practically considered only movements in the vertical plane at right angles to the fault, and gave methods of determining the vertical throw, but none to determine the horizontal movement. The horizontal displacements on the San Andreas fault were proved, without question, by the dislocations and offsets in roads, fences and pipes, where they crossed the line of the fault. Very naturally the cause of the earthquake was ascribed to this sudden movement and we shall see later that it accounts for the disturbance and supplies an abundant amount of energy to explain all the effects produced.

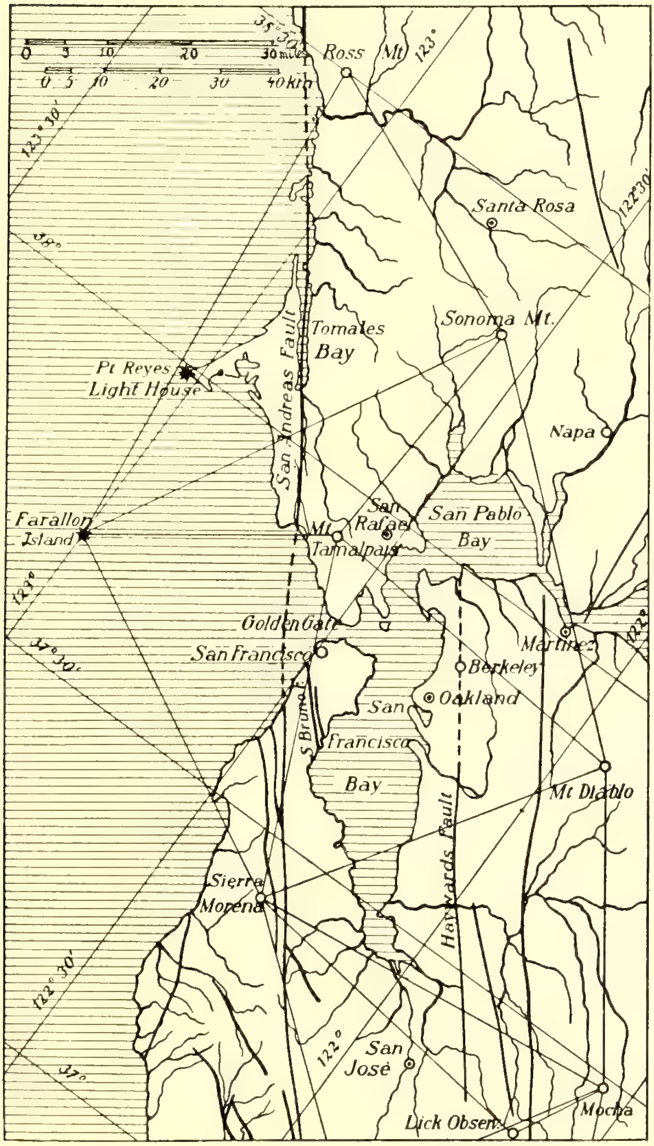
The field observations showed very clearly the dislocations and offsets at the fault line itself, but they were not competent to show how far from the fault the actual displacement extended. That the displacement gradually became less and less, as the distance from the fault-line increased, seemed probable, because a thorough exploration of the region failed to discover any other lines with offsets similar to those along the San Andreas fault,

and therefore it was presumable that blocks of the earth's crust were not shifted as a whole. Fortunately accurate geodetic surveys had been made throughout this region many years ago, and the Commission appealed to Mr. O. H. Tittman, Superintendent of the United States Coast and Geodetic Survey, to repeat the surveys and to determine the true displacements of the various stations of the surveys. Mr. Tittman realized the importance of this, and the work was carried out under the immediate direction of Messrs. Hayford and Baldwin. The results were published in detail in the report of the Commission, and we shall merely summarize them here.

The earlier surveys can be divided into two groups: I, those made between 1851 and 1866; II, those between 1874 and 1892. The survey after the earthquake (III) was made in 1906–7. The surveys extend from Mt. Diablo, thirty-three miles east of the fault-line, to the Farallon Lighthouse, twenty-three miles west of it, as shown in the map, figure 1.

All the surveys are connected through the common points Mt. Diablo and Mocha on the inner Coast Range, and the line between them, which is practically parallel with the fault-line. Dr. Hayford has shown that this line either has not moved at all, or has moved parallel with itself without changing its length; for astronomical observations at the times of the surveys show differences in its direction of only a small fraction of a second of arc—that is, within the limits of error of the surveys; and the distances of various points from it measured at right angles to its direction do not show a systematic change depending on their distances, which proves that it has substantially preserved its length without change. Although there is no evidence that this line has moved as a whole, evidence that it has not is also lacking; but fortunately for our purposes this is unimportant, as we are considering only relative displacements.

Survey II covers very well the region north of San Francisco, and in combination with survey III brings out clearly the displacement of a number of stations between the dates of these surveys. Without going into details the following table summarizes the displacements (which are practically parallel with the fault-line) undergone by the best determined points.



0 5 10 20 30 miles
0 5 10 20 30 40 km
Ross Mt
Santa Rosa
Sonoma Mt.
Tomales Bay
Pt Reyes Light House
San Andreas Fault
Napa
Farallon Island
San Rafael
San Pablo Bay
Mt Tamalpais
Golden Gate
San Francisco
Martinez
Berkeley
Oakland
S Bruno F.
San Francisco Bay
Mt Diablo
Haywards Fault
Sierra Morena
San José
Mocho
Lick Observ.

Fig. 1

Number of points	Average distance from fault East	West	Displacement between surveys I and II South	North
1	4.0 miles		1.8 feet	
3	2.6 miles		2.8 feet	
10	0.9 miles		4.2 feet	
12		1.2 miles		9.7 feet
7		3.6 miles		7.8 feet
1		23.0 miles		4.8 feet

These displacements are shown graphically in figure 2.

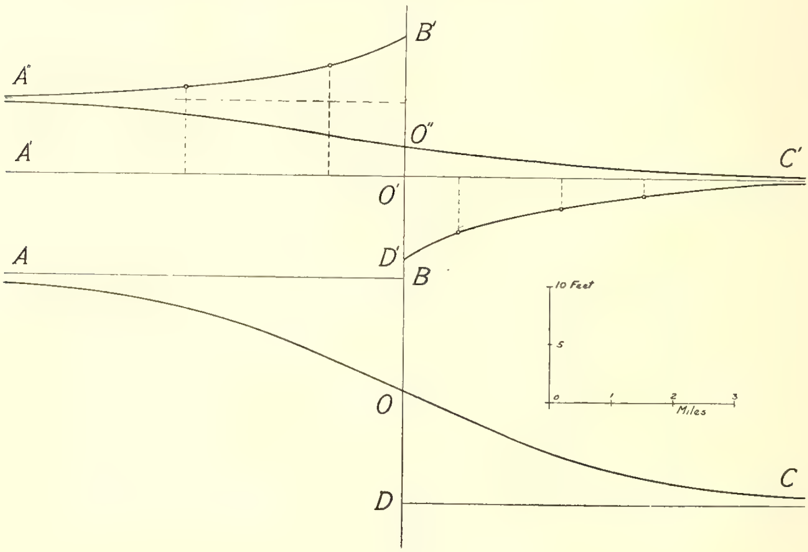


Fig. 2

The line $A'C'$ represents a line which was straight at the time of the second survey. At the time of the earthquake this line was broken at the fault, and its two parts were separated about 21 feet, taking the positions $A''B'$ and $C'D'$. Three points and the distant Mt. Diablo determine the right-hand curve; two points and the distant Farallon Light House, together with the fact that $D'B'$ must be 21 feet, determine that on the left. In the figure the distance scale is 1000 times the displacement scale because this difference is necessary to show the character of the displacements. The curvature of the lines is extremely small, the radius of curvature being nowhere less than 4000 miles, and

the greatest change in direction of any part of the lines between the two surveys being about one minute of arc. What kind of forces could have caused this movement? Gravity could not have been the immediate cause of the sudden and nearly horizontal displacements, nor could volcanic explosions; the only forces capable of producing such movements are elastic forces. Since the material composing the earth's crust is elastic, and cannot rupture until it is strained beyond its strength, it is evident that an earlier relative displacement of regions on opposite sides of the fault had set up an elastic strain in the intermediate zone, which exceeded the strength of the rock, causing the rupture along the fault surface; and that the rock on opposite sides of the fault, under the action of its own elastic stresses, then suddenly sprang back to positions of equilibrium, the opposite sides moving in opposite directions, and relieving the elastic strain. This is the only satisfactory explanation of the observations and determined displacements. If a curved line, AOC (fig. 2), continuous at O, and with its two sides exactly like the two lines $A''B'$ and $D'C'$, but bent in opposite directions, had been drawn on the ground just before the earthquake, it would have broken and straightened out into two lines, AB and DC, at the time of the rupture. The line $A'O'C'$, straight at the time of survey II, must have been changed into the line $A''O''C'$ before the rupture, and, as we have seen, into $A''B'$ and $D'C'$ immediately afterwards.

All changes in the shape of a solid body may be reduced to two types,—changes in volume, either compressions or extensions, and slipping of one part past another, as the various cards of a pack may be made to slip over each other. When a beam is bent, the convex side is stretched and the concave side compressed, and the elastic forces thus brought into play resist the bending; and if the forces which bend the beam are removed, the elastic forces will cause it to straighten out again. If the cards in our illustration are held together by an elastic cement, we readily see that when they are made to slip slightly over each other there will be a resistance to the movement and on releasing the disturbing pressure they will return to their original position. This kind of a change in shape, when each card be-

comes indefinitely thin and the number of cards indefinitely large, is called a *shear*.

When we notice the curvature of the broken line in figure 2, we are inclined to think that the rock was bent like a beam; but when we reflect that the breadth of the beam would correspond to the length of the fault, 270 miles, and the length of the beam to the distance from the fault to which the elastic strain extended, and which was probably not more than six, and certainly not more than ten miles, we see that the length of the beam would be so very short in comparison with its breadth, that the characteristics of a beam would be entirely lost. We must, therefore, look upon the elastic strain as a shearing strain alone, parallel with the fault.

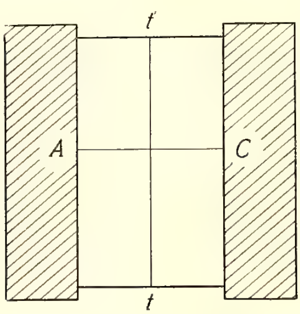


Fig. 3

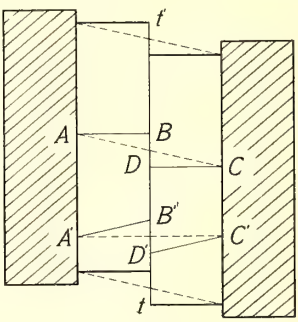


Fig. 4

We can imitate the movements experimentally. Two short pieces of wood were connected by a sheet of stiff jelly one-half inch thick, and two inches wide, and about three inches long, as shown in figure 3. The jelly was cut through along the line, *tt′*, by a sharp knife, and a straight line, *AC*, was drawn in ink on its surface. The left piece of wood was then shifted about one-half inch in the direction of *t′*, and a gentle pressure was applied to prevent the jelly from slipping on the cut surface. The jelly was sheared elastically and the line took the position *AC* shown in figure 4. On relieving the pressure so that the friction was no longer sufficient to keep the jelly strained, the two sides slipped along the surface *tt′* and the line *AC* broke into two parts, *AB* and *DC*. (The broken lines represent positions immediately before the slip, and the full lines immediately after it.)

At the time of the slip A and C remained stationary, and the amount of the slip, DB, equalled the shift which A had originally experienced. A straight line, $A'C'$ (fig. 4), was drawn on the jelly after the left side had been shifted, but before the jelly slipped along tt'. At the time of the slip, the same movement took place in the neighborhood of this line as near AC, and $A'C'$ was broken into two parts, $A'B'$ and $D'C'$; the total slip, $D'B'$, being equal to DB.

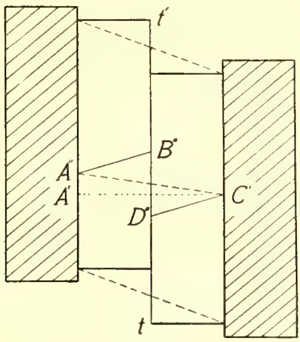


Fig. 5

A third experiment was tried; the left piece of wood was shifted one-half inch and a straight line, $A'C'$ (fig. 5), was drawn across it; it was then shifted one-fourth inch more and the straight line took the position $A''C'$. When the jelly slipped along the surface tt', the line broke into two parts, $A''B''$, and $D''C'$; the slip, $D''B''$, being equal to the total displacement of the left side. Two characteristics of the movement in the last experiment are to be noted; the total slip on the ruptured surface equalled the total relative displacement of the blocks of wood; and at the time of the slip the blocks remained stationary, and the whole movement was an elastic rebound of the jelly to a condition of no strain. These two characteristics could have been deduced from the elastic nature of the jelly without recourse to actual experiment. It is also to be noted that the displacements, measured from the line $A'C'$, were greatest at the fracture; that, on the right-hand side, they gradually diminshed to zero at C'; that the displacements on the left side were much greater than on the right; and that they gradually decreased

with the distance from the fracture, but never became less than the displacement, $A'A''$, of the left block after the line $A'C'$ was drawn.

The last experiment illustrates, as well as a simple experiment can, what occurred at the time of the California earthquake; the sudden fling of the rock when the rock fractured along the San Andreas fault was due to the elastic forces set up in it by an earlier relative displacement of the regions on opposite sides of the fault, just as the fling of the jelly was due to the elastic forces set up by the relative shifting of the wooden blocks. As already mentioned, observations in the field showed that at the time of the earthquake there was a relative movement of the two sides, at the fault-surface, amounting to about 21 feet. The surveys show that the actual displacements which took place between surveys II and III diminished as the distance from the fault became greater; on the east side the displacement practically died out at a distance of six or ten miles from the fault, and on the west side the displacement apparently became equal to that of the Farallon Light House at about the same distance. All the phenomena are in close accord with the last experiment described above. The main difference consists in the fact that a straight line across the fault on the earth's surface did not break up into two straight lines, as in the experiment, but into two curved lines. We ascribe this curvature to the fact that the forces which produced the displacement of the ground were applied below the crust of the earth, whereas in the experiment they were applied to the outer boundary of the jelly.

The elastic rebound near the fault-surface, of course, took place suddenly at the time of the earthquake; between surveys I and II, and between II and III, there were relative shifts of very extensive regions, the fault-line being the line of separation between them for the second interval; but the surveys do not determine whether these shifts took place suddenly at the times of the great earthquakes of 1868 and 1906, or whether they were the effect of a slow, gradual movement continuing through the years. The experiments we have described might have been varied, and instead of a slow displacement of the block, gradually setting up an elastic shear, we might have set up the shear

suddenly by a sudden displacement of the block; the movements at the time of the slip would have been exactly the same in the two cases.

We must turn to other considerations to determine which of the above cases represents the earth movements leading to the California earthquake.

A very important chapter in the history of the earth is concerned with the record of the various movements which have taken place in the crust. The vertical movements are thoroughly attested by the various heights to which strata, deposited under the sea, have been raised; and by the unconformities which exist in the geological column. The horizontal movements are shown by the compression of the strata into folds, and by great overthrust faults. That these movements have continued until recent time is shown by the existence of raised beaches, and other similar evidences; and that they have not been simply due to a general rising, or sinking, of the surface of the ocean follows from the fact that the elevations vary at different places. For instance, the Cretaceous strata of Maryland are now near the sea-level, whereas in the great plateaux of Utah and Arizona they have an elevation of about 8000 feet. Innumerable instances of the various elevations of strata once at the same level could be mentioned. Moreover, many of the raised beaches, which must have been horizontal when they were formed, are now tilted. We have excellent examples of this tilting in the account given by Baron de Geer of the raised beaches in Scandinavia; and in the tilted shore-lines of the old glacial lakes in the region of the Great Lakes. Mr. Gilbert's discussion of the tide-gauge readings at various points on the Great Lakes, and of the topographic changes taking place on their shores, shows, without reasonable doubt, that the tilting is going on at the present time; and that the difference of level between two points 100 miles apart and lying on a NNE and SSW line is changing by probably more than half a foot per century.

It is firmly established that since the beginning of geological history the crust of the earth has been in continual movement, rising in one place, sinking in another, here squeezed into folds, there somewhat stretched. It is generally assumed that these

movements are slow and continuous, but the treatises and textbooks on geology are lacking in a discussion of the question.

In his principles of geology Lyell argues in a general way in favor of the slow movements of the land, but he is concerned more particularly with opposing the catastrophic ideas that were current at the time. He points out that past actions are probably the same as those going on at present, that the continued growth of corals on coral islands indicates, according to the ideas of Darwin and Dana, a gradual subsidence and that no sudden depression amounting to as much as 100 feet could have taken place without the destruction of the life of the coral-building polyps. He also argues that after earthquakes along the South American coast, the land was found to be raised a few feet, and considers that the great elevation of the coast shown by raised beaches, etc., is simply the sum of these small movements. He adduces the creep as observed in coal mines and points out that the plastic floors of some mines are gradually squeezed up to fill the space between the pillars left to support the roof, and that this movement in general is slow and continued.

Great weight is put on the slow changes of level in the Scandinavian peninsula, which were at that time much discussed, the movements of the temple of Serapis at Possuoli, and other slow changes of level. Since Lyell's time, many other similar movements have been discovered. It has also been pointed out that mountain ranges have been raised across the courses of certain rivers, but that the elevation has been so slow that the rivers have been able to cut down their beds as fast as the mountains rose, and have thus preserved their original courses. The course of the Potomac River, for instance, has not been changed by the elevation of the Appalachians.

It is quite evident that these arguments do not distinguish between continuous slow movements, and a succession of small sudden displacements, and Lyell was rather concerned with combatting the older catastrophic theory and advancing the uniformitarian ideas of Hutton. But, nevertheless, the universal acceptance of Hutton's views, and the lack of evidence that the undoubtedly slow changes of level were the result of many small but sudden movements, has led to the general belief that the

earth's crust was subject to slow continuous movements. The existence of great folds in the rocks undoubtedly contributed to this belief; although the force of this argument does not seem to have been clearly stated. The idea was carried too far, and it was even supposed that the great displacements, which geologists have shown to exist at innumerable faults, were attained by a slow, steady, and long continued movement.

I am persuaded that besides the sudden fling when there is a slip on a fault, there exist in the crust of the earth slow and continuous movements not uniform, and not even always in the same direction, but still movements which are truly continuous, and have no trace whatever of sudden starts.

The weakest argument is based on the fact that many known movements of the land are extremely slow and are spread over long intervals of time, and that there are no indications at all that they are simply the sum of a number of small sudden displacements. Professor John Milne, in describing the reports giving information regarding the changes of level on the Japanese coast, states that some of his informants consider that these changes were due to a great earthquake, "although in no case has it been stated that the changes accompanied such disturbances." One might suppose that the continuous nature of the movement could be determined by a series of tidal observations. But many years must elapse before the movement can be detected at all, and therefore it is quite impossible to prove by this means that it has been actually continuous.

The strongest argument is based on the plastic deformation of the rock. The great overthrust faults, the folded and contorted strata, the existence of slaty cleavage, the thinning of the strata and the flattening of fossils, prove beyond question that the rock has been subjected to enormous pressures. Whatever may be the ultimate cause of this pressure, it is certain that its transmission from one part of the rock-mass to another is by means of elastic forces in the rock; there is always a certain amount of elastic compression or distortion under external force, which indeed determines the amount of force transmitted and is itself determined by the amount of the external force. If a book is placed on the table, there is a slight elastic compression

of the table itself which exercises an upward pressure on the book and supports it against the pull of gravity; and there is a general compression of the book itself, for each part must exert a sufficient elastic force on the part above to support its weight. When power is transmitted along a shaft, the force is applied at one end turning the shaft; the elastic shearing force thus brought into play is transmitted along the shaft, each part being slightly twisted on the part beyond it, and thus exerting on it a turning force. Elastic forces are essential to our well-being; we make use of them at every moment of our lives.

We must look upon the rock under pressure as suffering a certain amount of elastic compression, or distortion. Rock, in common with other substances, is not perfectly elastic, but has some plasticity, and under the long continued action of an external force it will gradually change its shape without fracture. We have evidence of this not only in nature but in the laboratory. When Messrs. Nagaoka and Kusakabe made experimental determinations of the elastic constants of various rocks they found a certain amount of plastic yielding even during the few minutes involved in their experiments. And Professor Adams has succeeded in deforming small specimens of marble without fracture by supporting them in a strong steel tube while subjecting them to enormous pressures. If, however, the rock had not been supported on its sides, the great pressures, as in certain methods of testing the strength of materials, would have cracked it into many pieces. Marble slabs over old graves, supported at their ends, have sunk slightly in the middle, not by elastic bending but by a plastic distortion.

We have then the following facts: the rock in the earth's crust has been subjected to strong forces; it is plastic; it is supported beneath and on the sides by the surrounding rock and above by the weight of the rock resting on it; therefore, as in Professor Adams' experiments, it must be slowly deformed; and by this yielding the elastic forces are reduced or at least prevented from increasing as rapidly as they otherwise would. The existence of faults proves that when the forces become too great fractures occur and, moreover, that sudden plastic deformations do not

occur; for if they did the elastic forces would be kept down below the breaking point, and fractures would be averted.

The objection might be made that rock at great depths and, therefore, under heavy pressure could not fracture, but might be suddenly deformed; but if it could suddenly change shape plastically, it could also change shape by a sudden slip along a fault. Moreover, the sudden plastic yielding implies either the sudden reduction of the forces resisting plastic deformation, which is contrary to our knowledge of the properties of matter, or the sudden increase in the deforming forces. We can readily picture to ourselves fairly steady forces like gravity, or the forces brought about by the disturbance of isostatic equilibrium; but the only sudden forces, except those caused by blows or by the release of elastic strain, are explosive forces, and no one would imagine that the great foldings of the strata were due to successive pressures brought about by a great number of explosions. And as the observed foldings and contortions of the rock are what we should expect from a slow plastic flow, it seems superfluous, to say the least, to ascribe it to sudden movements. And if there is a slow plastic yielding there are slow movements of the rock; for the movement of a given part of the rock must be equal to the movement of the rock in front of, or behind, it.

We can show that the elastic strains which caused the California earthquake were not suddenly developed immediately before the shock, but that the strain existed to some extent twenty-five and fifty years earlier. It should be noticed that in the first experiment with the jelly the elastic rebound of points on the right side of the fracture brought them to exactly the same position, relative to the right-hand block, that they held before the strain was set up. In the second experiment, where the relative positions were determined after the strain was set up, the jelly on the right was displaced downward after the slip. This is exactly what occurred in the movements on the eastern side of the San Andreas fault. The points on that side were displaced southward between the times of the second and the third surveys, showing conclusively that at the time of the second survey the ground was already in a state of elastic strain. This is brought out also in another way. The third experiment

shows that the total slip at the fault-plane, at the time of the rupture, is exactly equal to the total relative displacement of the blocks of wood; therefore, we must infer, since the total slip on the San Andreas fault amounted to about 21 feet, that the shift of the distant regions must have been as great; but it was found that between surveys II and III the shift was only 5.8 feet and between I and II 4.6 feet; that is, in all, only about 10.4 feet since the earliest surveys, some fifty years before the shock. We can therefore say definitely that the shift which set up the elastic strains which finally resulted in the earthquake had already accumulated to about half its final amount fifty years earlier; that between surveys I and II it increased to about three-quarters of its full amount, and that the last quarter was added between surveys II and III. In the experiments the elastic rebounds of the two sides were equal and in opposite directions. The surface rocks on opposite sides of the fault are not identical as is the jelly, but it is probable that at no great distance below the surface they are similar, which would lead us to expect *approximately* equal rebounds on the two sides. We have no determinations of the displacements just before the earthquake, and therefore no measures of the actual rebounds, but Professor Lawson has pointed out that if we assume the displacements to have been continuous and uniform during the interval between surveys I and II, and to have continued at the same rate up to the time of the earthquake, then the region about the fault would have been so far north at that time that the rebounds on the two sides would have been practically equal, just as with the jelly. It is hardly possible in view of the above history, of the relations just mentioned and of the difficulty of imagining forces capable of suddenly moving and stopping large areas, not to be convinced that the shift accumulated gradually.

To summarize, we may say, that for many years, perhaps for a century, a slow relative movement to the north of the region under the Pacific Ocean, just west of California and comprising a part of the coast, was taking place and setting up a shearing strain in the coast region, which finally became too great for the rock to endure; that a fracture occurred along an old fault-line and that the two sides sprang back towards positions

of no strain under the action of their own elastic stresses, the amount of the sudden rebound diminishing as the distance from the fault-line increased, and being no longer measurable at a distance of less than six miles from it.[1]

The summary above describes all the mass movements that occurred at the time of the earthquake in a zone about fifty-six miles wide, and excludes from that zone the movements of blocks of the crust as a whole. The gradual diminution in intensity of the disturbance to the eastward of the zone, with the exception of alluvial tracts, where the terrane caused an increase, indicates that no fractures occurred to the eastward; and the intensity at the Farallon Light House shows that no fracture occurred for some distance west of it. As far, therefore, as negative evidence goes, no block movements occurred; and, indeed, at the time of the earthquake all the known movements can be accounted for without assuming them. Moreover, the lack of dislocations on other faults not far from the San Andreas fault is a very strong argument, from an observational standpoint, against block movements at the time of the California earthquake.

A great amount of energy was set free at the time of the earthquake; the law of the conservation of energy points out that it was not created at that time, but must have existed earlier in a potential form. The sudden earth movements were practically horizontal and, therefore, it could not have been in the form of gravitational energy, the energy which would have been liberated if a block of the earth's crust had suddenly sunk. But we have seen that the earth movements were merely elastic rebounds, and therefore the energy must have been in the form of potential energy of elastic strain; a form nearly related to the energy stored in the spring when a clock is wound up, or the energy in a bow when the arrow is drawn back, ready to fly. It is an easy matter to calculate the amount of energy contained in the rock in the form of elastic deformation by the work done as the two sides of the fault flung back to positions of equilibrium. This equals the total elastic force multiplied

[1] This conception of the causes of the California earthquake of 1906 was first stated by Professor Lawson in the *Report of the California Earthquake Commission*, vol. 1, pp. 147–151. It was developed further in the second volume of the report.

by half the relative slip. If we take the length of the fault at 270 miles, its depth at twelve and a half miles, and the average slip at thirteen feet, we find that the work done was 130,000,-000,000,000,000 foot-pounds. It is not surprising that the liberation within a few seconds of this enormous amount of energy should be followed by such great destruction in the megaseismic district, and that seismographs in all parts of the world should record the disturbance.

Energy is never created; it merely changes its form. Whence, then, came the energy of elastic strain which existed in the great rock-spring before the earthquake? We have ascribed it to the slow movements of the crust and of the underlying material; but the question still persists, Whence came the energy of these slow movements? It may have been gravitational, as we shall see a little later when we consider general suggestions that have been advanced to account for earthquakes, but we cannot answer with confidence. If we could follow this energy, step by step, back into the infinite past, we could solve the riddle of the physical universe.

Let us now turn our attention to the manner in which rock breaks along the fault-line.

Since the fracture results from elastic strains due to slow displacements of neighboring regions, it is practically certain, on account of irregularities in the displacement and in the character of the rock, that the stresses will not reach the limiting strength of the rock over the whole area of the fault, or even over a large fraction of it at once, but will begin in a very limited area, and extend from there at a rate not greater than the velocity of compressional elastic waves in the rock. When the rupture occurs at a point, or a small area, the elastic stresses are no longer supported there, and are therefore transferred to neighboring points, which in turn give way, and thus the rupture spreads along the fault-surface until the elastic strains are so reduced that they can carry it no further.

But the transfer of stress is not instantaneous; time is required for the successive parts of the rock to be sufficiently displaced to bring the strain in their neighborhood to the actual breaking limit, and the amount of time necessary to accomplish

this depends on the elasticity of the rock and on its density, on exactly the same quantities, which, we shall see later, determine the velocity of propagation of elastic waves; so that it is impossible for the fracture to extend more rapidly than the rate of propagation of the fastest elastic waves, which are of the compressional type, like the waves of sound; and in general it would extend less rapidly. It is clear that, if the strains were everywhere very close to the breaking limit, a very small movement and therefore a very short time would be necessary to bring the strain to that limit; whereas, if the strain were further from the limit, a greater movement and a longer time would be needed. This is probably one reason why some earthquakes of small intensity last for a number of seconds.

The progressive extension of the fracture is entirely in accord with our general experience. When a bridge or structure collapses, the break always starts at some particular point and extends from there; and the time taken for the complete downfall is far greater than would be necessary if the break occurred everywhere simultaneously, and workmen often have time to spring from the falling structure and save themselves. An avalanche or landslide begins in a small way and gathers material and momentum as it descends. When a chair breaks it does not often happen that there is a sudden collapse, but one part breaks after another, and the occupant usually has time to spring to his feet. When an ice-jam in a river gives way, one part always yields first. When a sheet of paper is torn the tear begins at one side and passes across the sheet. Even when gunpowder is fired, a measurable time is necessary for the explosion to spread from its starting point to other points of the mass.

Two instances have been found where the progression of a crack in the ground, or rock, has apparently been seen. The following is taken from the "Sun" newspaper, of Attleboro, Mass., of January 23, 1903:

"The experience of the town of Whitman was repeated by Attleboro yesterday, when an earthquake or frost crack or something of the kind made its appearance. There was a hollow rumbling, a shaking of buildings, a small-sized panic among

east-side residents, and a fissure opened in the ground of great depth and unknown length. . . . . The disturbance . . . was immediately followed by the appearance of the crack, which did not open simultaneously its whole length, but gradually, from its northern to its southern terminus."

Professor Niles, describing the expansion of the rock in the quarry at Monson, Mass., and the accompanying cracks, writes: "These cracks, or rents, are more commonly formed slowly, but sometimes suddenly."

It is interesting to note that Mallet believed the great Neapolitan earthquake of 1857 to be due to a fracture in the underlying rock, which began in a limited area and extended to greater distances.

Indeed, the progressive method of breaking is general, as it depends upon the elastic properties of solids. Absolute rigidity would be practically necessary to ensure simultaneous rupture over a very large area. It may be objected that it is trivial to emphasize the difference of a few seconds in the time of rupture at different parts of the fault; but the difference is not so very small. If the rupture of the San Andreas fault began near its middle point, it must have taken at least half a minute, and it may have taken more than a minute, to reach the ends of the fault; and moreover, deductions based on the supposed simultaneity of fracture have led to conclusions regarding mass movements, the place of origin of the vibrations, and the interpretation of instrumental records, which are quite out of harmony with the conceptions advocated here.

As the different parts of the same fault do not fracture simultaneously, so there is no probability of neighboring faults fracturing at the same time. If two faults are only a few miles apart, it may happen that the relief of strain at one will increase the strain at the other sufficiently to start a rupture there, if it is already strained nearly to the limit. The vibrations from one fracture, under the same conditions, might start the rupture of a second. In all these cases the rupture begins in a very limited area of a single fault, and extends along the same and perhaps to other faults, but never at a greater rate than the velocity of compressional elastic waves; as this velocity may, in some

instances, be as great as four miles per second, it is quite clear that only the most accurate time observations could serve to determine the starting point of the rupture; and that the majority of observations would not be accurate enough to show that disturbances did not start simultaneously throughout the megaseismic district.

At the time of the rupture the rigidity of the rock would not permit very large movements of the two sides of the fault until the fractured surface had greatly increased in size; but when the large movements came they would cause the severest part of the shock. The friction at the fault would make these movements irregular, so that the vibrations sent out would not be a steady, strong series, but would vary so much in intensity that they would produce the effect of strong shocks separated by weaker intervals. At the time of the California earthquake, the severest part of the disturbance did not come until thirty seconds after the beginning of the fairly strong shocks; and it was felt from thirty to sixty seconds. The time necessary for the sides of the fault to reach their positions of equilibrium under the elastic forces, free of friction, would have been only a little more than two seconds. The duration of the severe shocks at any place was partly due to friction on the fault-surface, partly to the time necessary for the extension of the fracture, and partly to the arrival of shocks from more distant parts of the fault.

The friction of the two sides of the fault when the dislocation is taking place, and their sudden starting and stopping (the latter due largely to the friction), are the causes of the vibrations which are propagated elastically to a distance; and they all have their origin in the rupture surface. It has been suggested that the origin of the vibrations may lie in a volume and not on a surface; and that the sudden folding of the rock or the movement of a block as a whole would cause elastic vibrations to emanate from the whole volume moved. This idea seems erroneous. If the rock were sufficiently plastic to fold very rapidly under the compressive forces it would not be sufficiently elastic to send out vibrations; and if the rock yielded elastically to a suddenly applied force, the vibrations would start from the boundary where the force must be applied. We shall see that blocks do not

move as a whole; but even if they did, vibrations would not originate in their volume any more than vibrations would originate in the volume of any other body falling under gravity; for vibrations are started, not by simple velocity, or acceleration, but by the differential velocity in contiguous elements. Friction starts vibrations by causing rapid changes of velocity at the surface of the slipping mass. If a block were suddenly started, or stopped by elastic forces, the vibrations must start from the boundary, where alone the forces could be applied.

We may now sum up our general results. The observations of the California earthquake and the deductions drawn from them based as they are upon the elastic properties of rock and upon the well-known relative movements of different parts of the earth's crust, have led to certain general conceptions of the mass movements which take place before and at the time of tectonic earthquakes, which may be expressed as follows:

1. The fracture of the rock, which causes a tectonic earthquake, is the result of elastic strains, greater than the strength of the rock can withstand, produced by the relative displacements of neighboring portions of the earth's crust.

2. These relative displacements are not produced suddenly at the time of the fracture, but attain their maximum amounts gradually during a more or less long period of time.

3. The only mass movements that occur at the time of the earthquake are the sudden elastic rebounds of the sides of the fracture towards positions of no elastic strain; and these movements extend to distances of only a few miles from the fracture.

4. The earthquake vibrations originate in the surface of fracture; the surface from which they start has at first a very small area, which may quickly become very large, but at a rate not greater than the velocity of compressional elastic waves in the rock.

5. The energy liberated at the time of an earthquake was, immediately before the rupture, in the form of energy of elastic strain of the rock.

These statements, which may be called the *elastic rebound theory of tectonic earthquakes,* do not broach the original cause of earthquakes, which lies in the source of the slow movements

accumulating the elastic energy, but merely give the *modus operandi* of the accumulation and liberation of this energy.

They are opposed to Lieut. Colonel Harboe's idea of focal lines, which assumes that the fracture extends practically as far as the earthquake is felt; and to the block movements of several writers, who suppose that the earth's crust breaks up into individual blocks, each of which moves as a whole to a new position of equilibrium.

It must not be supposed that earthquakes are caused only by horizontal movements on a vertical fracture, as in the case of the California earthquake. Any kind of a fracture is sufficient, and the movements may be horizontal, vertical or oblique. When rocks have been folded in the earth's crust it is not uncommon to find scratches on the limbs of the folds resulting from the slipping of the strata upon each other. Professor Smoluchowski has suggested that this slipping might be a cause of earthquakes. It seems quite certain that, as the rocks were being folded by horizontal pressure, the friction would at first prevent any such slipping of the strata; but as the elastic forces become stronger, slipping would occur suddenly with an elastic rebound of the adjacent strata, which would constitute an earthquake. It is probable that the elastic strains set up in this way and the consequent rebounds would never be very great and, therefore, that severe earthquakes are not originated in this way.

Let us glance for a moment at the accounts of some other great earthquakes and see if the movements of the ground which accompanied them were similar to those found at the time of the California earthquake, and if the ideas of elastic rebound which we have developed can be applied to these.

A very severe earthquake occurred in the Province of Cutch, near the mouth of the river Indus, in 1819. An extensive, flat plain, known as the Rann of Cutch, only a few feet above the level of the sea, and which was indeed formerly a sea bottom, occupies a large area in this region. It is traversed by a small distributary of the Indus, called the Pooraun or Koree, but for some years before 1819 no water had flowed through this channel on account of dams built across it further up. The great shock

occurred a little before seven o'clock in the evening of June 16 and was so severe that all the villages in the neighborhood were destroyed, and a mosque at Ahmedabad, about 250 miles to the east, which was erected nearly four hundred years earlier, fell to the ground; the vibrations of the earthquake were felt in north-west India, to a distance of eight hundred miles.

In the midst of the Rann and near the old bed of the Pooraun, stood the Sindree fort, where customs were levied on commerce. At the time of the earthquake the land in the neighborhood of this fort sank a distance of about ten feet. Water apparently burst up from the ground and rolled in from the sea by the channel of the Koree; an immense lake was formed, of unknown extent east and west but about six miles from north to south, which was a few feet deep and covered all but the highest parts of the region. Two or three miles to the north of Sindree appeared a scarp, ten or twenty feet high, running in an easterly and westerly direction for an unknown distance, but apparently about fifty miles, which was called by the natives "The Allah-Bund," or "Mound of God." Mr. A. B. Wynne, in the *Memoirs* of the Geological Survey of India, has described the geology of the region, and collected the available information regarding the earthquake. He concluded that the land south of the Bund had sunk, but that the Bund itself did not represent an elevation, as was generally supposed at the time of the earthquake, but was merely the scarp left by the depression of the land to the south. This depression did not extend indefinitely, but from the depth of the water which accumulated there it is evident that the greatest depression occurred near the Bund and diminished toward the south. Indeed, there are some reports of a slight elevation about eighteen miles south of the Bund, though they are probably not very reliable. No account is given of any change on the seacoast, forty or fifty miles to the southwest, except the apparent deepening of the channel of the Koree, which may be due to scour. A tidal wave would undoubtedly have followed a sudden depression of the coast, but none was mentioned. The water which appeared over the plain was supposed, by some, to have come from the sea through the Koree; but this does not require a tidal wave, for the level of the new lake was

so low that in August, 1827, at the time of the monsoons, the sea water was driven up the Koree and made the lake brackish. Earlier in the summer it was fresh on account of the floods mentioned below.

In 1844, Captain Baker, of the Bengal Engineers, made a map and section of this region. "On the 11th of July he found the 'mound' where cut through by the Pooraun (or Koree), nearly four miles in width, but in other places it was said to vary from two to eight miles. Its greatest height was on the border of the lake, above the level of which it rose 20½ feet. From this elevation *it gradually slopes to the northward till it becomes undistinguishable from the plain.*"

In 1826 heavy floods caused the Indus to break through the dams and to pour down its former channel across the Bund. Mr. Wynne thinks that if the Bund had actually been elevated, the stream would not have crossed it, but would have flowed to the side. Professor E. Suess accepts Mr. Wynne's explanation and considers that there was no elevation of the Bund, but that "it is simply a case of the eruption of the subterranean water and the consequent subsidence of a sharply defined portion of the muddy ground."

Dr. R. D. Oldham, having found a tracing of Captain Baker's map and section, which were apparently unknown to Professor Suess, as he does not mention them, concludes, after a review of Mr. Wynne's memoir, that the Bund was actually elevated ten feet at the scarp line with a gradual slope down towards the north and that there was an approximately equal depression immediately south of the scarp. He writes: "On the other hand, and opposed to the arguments which can be urged against an elevation, we have the map and section, and the very definite statement, evidently based on careful leveling, that there was an actual upward slope of the ground immediately behind the southern scarp of the Allah-Bund. There seems, consequently, good grounds for maintaining the older view that the Allah-Bund was an elevated tract, but there can be no doubt that the estimates of its height do not correctly represent the amount of elevation, but of the sum of this and the depression which certainly took place to the south. The former cannot have exceeded

ten feet, the latter amounted to as much or more, and the two together represent the estimates of the height of the barrier as seen from the south, estimates which range up to 20½ feet.''

When we consider the general character of the movement which took place at the time of this earthquake, Professor Suess' explanation seems entirely inadequate. Is it possible that the subsidence of a portion of the land due to the squeezing out of the contained water could present the characteristics noticed at the Rann of Cutch? We have a well-defined scarp some fifty miles in length and about twenty feet in elevation sharply dividing the land which was depressed from the region not so affected; we find the subsidence was greatest at the scarp and diminished towards the south, with no other scarp limiting its area; and we find that the lake so formed was not merely a temporary lake due to the sudden supply of water and quickly drained, but that it remained as a permanent lake for some time and that it is still occasionally flooded either by fresh water from the rains and surrounding streams, or by salt water driven in from the sea by the southwest monsoons, conditions which did not exist before the earthquake. And we have Captain Baker's positive statement that the Bund slopes downwards towards the north, and his section shows the slope, which was, however, so gentle that it could not have been detected by the eye alone.

In view of our present knowledge, I think we may represent very simply the movements which took place at the time of this earthquake as follows:

The Rann of Cutch, formerly below the sea level, was gradually raised by vertical forces which were stronger toward the north. An elastic shearing strain was thus set up which finally resulted in a rupture of the rock along an east and west line, with an upward fling of the northern side to form the Bund, and a corresponding downward fling of the southern side, to form the lake, the total relative movement being about twenty feet, practically the same as the relative horizontal displacement at the time of the California earthquake. It seems rather strange that Professor Suess, who pointed out so clearly the relations of earthquakes to fault-lines, should not have seen that in this

case the scarp was merely the surface indication of the general movement on an underlying fault.

On January 23, 1855, a severe earthquake shook the region about Wellington, New Zealand. A very interesting account of the changes produced at the time of this earthquake is given by Lyell, from which the following is taken.

Wellington lies near the southwestern corner of the peninsula which puts out from the northern island and is bounded by Cooks Strait. In the middle of this peninsula lies the broad, flat Wairarapa Valley, trending northeast and southwest. It is bounded on the northwest by the Remutaka Mountains and is separated from them by a great fault. These mountains extend further south than the plain and form the western side of Palliser Bay. After the earthquake, it was found that the mountains along the line of the fault for a distance of about ninety miles had suddenly risen nine feet and large fissures appeared between the rock and the soft material of the plain. An engineer, who was engaged at the time in making a road along the side of Palliser Bay, found clear evidence, by the height of a line of shells clinging to the rock, of the elevation of the mountains, but apparently no evidence was found of a counter movement in the plains. This, however, is not surprising, as the slight variation in slope, which alone could have shown a depression of the plains, would easily have eluded detection; and, moreover, the softer material of the plains may have been dragged up by the rock. The northwest coast of the peninsula, about twenty-three miles from the fault-line, experienced no elevation, but Port Nicholson, about half-way between the west coast and the fault, was raised about four feet on its western and five feet on its eastern shore. Lyell looks upon this variation in elevation of the land at the time of the earthquake as showing how the strata may be tilted by varying amounts of elevation, but I think we are justified, with our present knowledge, in looking upon this as an example of elastic rebound, and not necessarily a step in the general tilting of the rocks.

New Zealand is a land of many faults. They have been more thoroughly studied in the South Island, where they have very materially influenced the topography of the region. Indeed, the

topographic features there are very similar to those of the great San Andreas rift, described in the report of the California Earthquake Commission. Parts of the South Island are subject to frequent and violent earthquakes, which have resulted from movements along these faults; and, it is most interesting to note that surface dislocations at the time of earthquakes had revealed many of these faults to the inhabitants, by whom they were called "earthquake rents," before they were known to geologists. Some of these faults continue across Cooks Strait and apparently connect with known faults on the North Island. One of them is the fault on the side of the Remutaka Mountains, on which the movement of nine feet occurred at the time of the earthquake of 1855. Three of the faults converge in the neighborhood of Wellington, and it is quite possible that some displacement occurred there at the time of that earthquake, but we have no account of it, and it seems probable that if there had been any distinct vertical movement on these faults it would not have been overlooked.

Displacements on faults reaching to the surface have taken place at the times of many earthquakes. For instance, the great Owens Valley earthquake of 1872, when there was an increased elevation of the Sierra Nevada along its eastern face; the earthquake of September 1, 1888, when fences were broken and offset from five to eight feet at the Clarence fault in the South Island of New Zealand; the Mino-Owari earthquake of 1891, when a great fault appeared across the main island of Japan, with both vertical and horizontal displacements; the Sonora earthquake of 1877, when two faults appeared on opposite sides of the mountains in the Sonora Province, Mexico; and the Nippon earthquake of 1896 in Japan, where movements also occurred on two distinct faults ten or twelve miles apart; and many others might be mentioned. At the time of all these shocks there were very evident displacements along the faults.

The Cutch and Wellington earthquakes offer positive evidence in favor of the gradual dying out of the displacement as the distance from the fault increases; the Clarence, the Owens Valley and the Mino-Owari earthquakes support the idea by negative evidence, inasmuch as no other faults were found to limit the

movement and to suggest the displacement of a block between two faults; the Sonora and Nippon earthquakes distinctly suggest movements of a block, but we shall see, when we consider the elevation or depression of mountain ranges, that these earthquakes may be explained satisfactorily without assuming such a movement.

In the case of the California earthquake it would have been impossible to prove that the elastic rebound gradually died out with increased distance from the fault, if it had not been for the successive exact surveys which were made in this region. The change in the amount of displacement diminished very slowly with the distance from the fault; the difference in a distance of a thousand feet in the neighborhod of the fault, where it was greatest, was only about six inches. It is not surprising, therefore, that the data regarding other earthquakes, where no such surveys were made, are, with the exception of the Cutch and Wellington earthquakes, insufficient to show a similar distribution of the earth movements. But the data in no way oppose the idea; and the positive evidence and the general reasoning seem quite strong enough to establish it.

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* Univ. Calif. Publ. Bull. Dept. Geol., vol. 6.

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